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SOME CHARACTERISTICS OF ORGANIC CONTENT OF ROCKS[1]

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ABSTRACT

The organic material in samples from a large number of different formations was studied by distilling them in the closed tube. The presence of organic substances of various types was indicated by odors of oil or visible oil, odors of scorching, odors of ammonia, and possibly in some cases by white sublimates. It is probable that one or more of these types are the source materials of oil. Although it is not possible to determine from the megascopic examination of a given sample what type of organic matter it contains, there are some general relationships between lithologic character and organic content. Dark rocks in general contain more organic matter than light. Shales, especially if greenish gray, are more likely to yield ammonia than limestones, and limestones are more apt to yield an odor of scorching than shales.

INTRODUCTION

Although it is generally conceded that oil has formed from organic matter, geologists have not agreed upon the particular type of material from which it has originated. If the rocks which generate oil and gas could be recognized by their characteristics, it should be possible to estimate the oil possibilities of untested regions by examining the strata associated with the prospective producing horizons. A practical achievement such as this is presumably the ultimate aim of the investigations regarding the origin of oil and gas.

In ascertaining whether sufficient source material was associated with a reservoir rock in a given area, it would be necessary to examine

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the strata above and below the horizon of the reservoir for a considerable distance down the dip. Since the nature of the organic content of rocks may vary rapidly both vertically and horizontally, it is evident that a great number of samples would have to be studied. Hence tests which were long and complicated, or which would require samples of large volume, would not be of much practical value for this purpose. What is needed is a procedure that is simple and rapid, and can be carried out in the field. For these reasons the distillation of small samples in closed glass tubes seems to be the most promising method of investigation. Closed tubes have of course been used by other investigators, notably by Takahashi.[3] Trask[4] has also described some distillation tests.

The present paper is based on closed-tube tests of more than 700 samples of shales, limestones, and dolomites. These samples were obtained from seventeen different states, and rocks of all the geologic periods since the beginning of the Cambrian are included. Because of the large number of rock types, periods and localities represented, it is probable that this investigation has revealed most of the important types of organic matter in rocks, as far as these are disclosed by closed-tube tests, and it is also likely that one or more of these types are the source rocks of the commercial accumulations of oil or gas. The chief purpose of the present paper is to describe the varieties of organic matter observed and the character of the rocks in which they are likely to be found.

DESCRIPTION OF TYPES OF ORGANIC MATTER

Definitions.—As the terms bituminous, asphaltic, and carbonaceous have been used with varying meanings, it may be well to define them before proceeding. In this paper the term "asphaltic" is used to indicate the presence in the pores or crevices of the rock of dark colored, solid, or very viscous hydrocarbons which become fluid without distillation on gentle heating. The term "bituminous" is applied to rocks which contain organic matter other than oil, asphalt, or waxy substances, and which when heated in the closed tube yield oil or an odor of oil. "Carbonaceous" refers to rocks which yield tarry substances or a tarry odor when distilled, owing to their content of coaly material.

Bituminous material.—When a richly bituminous rock is distilled the oil formed by the distillation accumulates in the tube just behind

[3] Takahashi, "The Marine Kerogen Shales of Japan," *Sci. Rept. Tuhoku Imp. Univ.*, Ser. 3, Vol. I (1923), pp. 53–156.

[4] Parker D. Trask, *Origin and Environment of Source Sediments of Petroleum* (1932).

the water. Generally the lightest constituents of the oil are partly mixed with the water, while the heavier and darker fractions are towards the hot end of the tube. By looking down the tube droplets of oil can be seen issuing as a fine mist from the sample and condensing on the sides. The volume of oil produced by the distillation of course varies enormously, and in many cases it is so slight that no distillate is visible and only the odor can be detected. These rocks which yield only an odor of oil on distillation are much more abundant than those which give a visible volume of the distillate. In most regions the total thickness of strata yielding visible oil on distillation is only a few per cent of the total thickness of the sedimentary column of the area. The areal extent of the bituminous beds varies greatly. Some are thick, but lenticular and non-persistent; others cover vast areas. The classic example of a persistent bituminous formation is of course the Chattanooga shale. Some of the thin bituminous shales or limestones overlying certain Pennsylvanian coals are also highly persistent.

It appears that it is very difficult if not impossible to determine by megascopic examination whether a given rock is bituminous or not. In some cases a group of samples of shale of almost identical appearance will prove on testing to be in part bituminous, in part non-bituminous. It is, however, possible to state that certain types of rock are much more likely to be bituminous than others. As would be expected, the darker the shade of a rock, the more likely it is to be bituminous. On the other hand, many black or grayish black shales and limestones are not bituminous, and many shales and limestones of a normal bluish gray or brownish color, by no means dark in shade, yield considerable visible oil on distillation. Although bituminous matter is widely distributed in both shales and limestones, it is more common in the shaly, earthy, and dense limestones than in the purer, crystalline types. Many richly bituminous shales are finely laminated, fissile, brittle, and weather light gray or purplish brown. Dense, black limestones with chalky aspect are also in many cases bituminous.

It is generally supposed that red strata are devoid of organic matter. Bituminous rocks are evidently of both continental and marine origin. For example, the Triassic of the Connecticut Valley, which is presumably entirely of terrestrial origin, contains some bituminous beds. The bituminous material of rocks is not necessarily destroyed by intense folding and overthrusting, even in Paleozoic rocks. In the vicinity of Ringgold, Georgia, which is in an area of overthrusting and very steep folding, the Chattanooga shale yields considerable oil on distillation, and it is reported that there is a seep of very light oil in the outcrop of this formation at this locality.

Carbonaceous rocks.—Some rocks yield a tarry distillate or a tarry odor when distilled. Such strata generally contain streaks or bits of coaly material or the imprints or carbonized remains of wood or leaves. They are also commonly associated with other evidences of a continental origin. Such strata are absent in the formations associated with the producing rocks of many important oil fields, and it does not seem likely that they are important source rocks of oil, although gas may be generated in them.

Rocks yielding ammonia on distillation.—Rocks yielding an odor of ammonia on distillation are more common than those yielding visible oil, and much more common than the carbonaceous strata. The materials which generate the ammonia when heated are comparatively rare in limestones, but occur in shales of various shades, even those which are light gray. Greenish gray shales are especially likely to contain this ammoniacal material.

Odor of scorching.—Organic matter which gives an odor of scorching in the closed tube is of common occurrence in limestones, but is rarely found in shales. It occurs in both dense and crystalline limestones, but is found to be less common in crystalline limestone of lighter shades. Many very dark, hard, crystalline limestones give the odor of scorching when distilled.

Odor of roasting coffee.—Some dense limestones give in the closed tube an odor resembling that of roasting coffee, but this is comparatively rare compared with the other odors previously mentioned.

Sublimates.—Many samples of limestone and shale yield on distillation a ring of white sublimate, which accumulates on the hot side of the tube from the water. It is due to native sulphur and possibly also to ammonium compounds, and may indicate that the rock contains organic matter. In some cases the same sample gives two different sublimates.

Sparks.—When crushed samples of some rocks are heated to redness in the closed tube, allowed to cool below red heat, and then poured out while still hot, sparks or glowing bits of rock become visible. This evidently indicates that a carbonized organic residue is present, which ignites on coming in contact with the air.

Sulphur fumes.—Sulphur fumes are given off by many shales and limestones when distilled. In most cases they probably come from the decomposition of pyrite, and may not indicate the presence of organic matter.

Bituminous odors from freshly fractured rocks.—A bituminous or fetid odor may be detected in a number of rocks which have just been broken or crushed. This odor is of course not produced in the

closed tube, and should be distinguished from the odor of oil produced on distillation. Some rocks which give the bituminous odor when crushed yield oil and an odor of oil in the closed tube. This is true of some samples of richly bituminous rocks, such as the Chattanooga shale. On the other hand, many dark, hard limestones yield a bituminous odor when broken, but when distilled in the closed tube produce neither visible oil nor an odor of oil, although they commonly give the odor of scorching. Nearly black crystalline limestones which generate the bituminous odor when broken are likely to decrepitate and give an odor of scorching when heated in the closed tube. If the bituminous odor is due to oil or similar hydrocarbons, as seems probable, the common association of this odor with rocks which yield the odor of scorching in the closed tube suggests that possibly these hydrocarbons have been generated from the same organic materials which furnish the odor of scorching on distillation.

Asphaltic rocks.—Rocks which contain waxy or asphaltic substances will give visible oil and an oily odor when distilled in the closed tube, and in the case of sandy shales and limestones of some porosity it is sometimes difficult to tell from the closed-tube tests alone whether the oil comes from the distillation of bituminous or asphaltic material. Since asphaltic and waxy substances are formed from the alteration of oil, they can not be considered an original source of oil.

A partial list of the distillation tests made in the course of the investigation is given in Table I.

CONCLUSIONS

1. The odors, distillates, and sublimates given by the distillation of rocks in the closed tube indicate that several types of organic matter are of rather common occurrence in the formations associated with the producing horizons of oil fields. These types are the bituminous materials, yielding oil or an odor of oil on distillation, the materials yielding an odor of ammonia on distillation, those yielding an odor of scorching, and those giving whitish sublimates.

2. Bituminous matter is found widely distributed in both limestones and shales, is more common in dark rocks than in those of a light shade, and is more likely to occur in dense limestones than in those which are crystalline.

3. Materials yielding ammonia on distillation are common in shales, even in those which are light-colored, but rare in limestones. Materials yielding an odor of scorching, on the other hand, are rare in shales, but common in limestones.

TABLE I

PARTIAL LIST OF DISTILLATION TESTS

Explanation.—In the five right-hand columns of Table I, x indicates that the characteristic is barely noticeable or present only in traces. xx that it is fairly distinct or present in moderate quantities, and xxx that it is strong or abundant. If the characteristic was not observed at all, the appropriate space is left blank. If all six right-hand columns are left blank, this indicates that the results of the tests were negative, or, in other words, that the sample was tested, but that no indications of an organic content were observed. In the column headed "Kind of Rock," *sdy.* means sandy or silty; and *cryst.*, crystalline. In the column headed "Color of Rock," *gr. gy.* means greenish gray; *wh.*, white or light gray; *med. shade*, medium shade; *ra. li.*, rather light; and *gr. bl.*, grayish black.

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
	Samples 1–93, Chester series (Upper Mississippian), western Kentucky								
1	Top of Paint Creek form., Lacon	dense ls.	wh.					x	
2	Paint Creek, Lacon	sh.	med. shade						
3	Paint Creek, Grayson Co.	dense cryst. ls.	med. shade				x		
4	Renault-Paint Creek, Bucksville, Logan County	dense cryst. ls.	med. shade						
5	Just below Bethel ss., between Garfield and Rosetta, Breckenridge Co.	sh.	gr. gy. dark	x				xx	
6	About 40 ft. below Cypress ss., SSE. of Bethel, Breckenridge Co.	sh.	black	xxx	xx				xx
7	Cypress form., near Lacon	sh.	gr. bl. gr. gy.					xx	
8	Cypress, 3 mi. S. of Lacon	sh.	dark						
9	Base of Cypress, Lacon	sh.	gr. bl.						
10	Top of Cypress, Lacon	sh.	ra. li.						
11	Top of Cypress, Grayson Co.	sh.	dark						
12	Base of Cypress, Royal	sh.	gr. bl.	xx					
13	Paint Creek form., Richelieu, Logan Co.	ls. shaly dense	wh.						
	Samples 14–17, Cypress form., Richelieu, Logan Co.								
14		sh. sdy.	med. shade					x	
15		sh.	dark					xxx	
16		sh.	dark						
17		sh.	dark						
18	Asphaltic ss. from Cypress ss., N. Logan Co.	ss.	dark	xxx	xx				
19	Base of Cypress, Richardsville, Warren Co.	sh.	gr. gy. med. shade					xx	

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
20	Base of Bethel, Breckenridge Co.	sh.	gr. gy. dark	xx				xx	
21	Top of Cypress, Grayson Co.	sh.	dark						x
22	Golconda form., Lacon	sh.	dark						x
23	Golconda form., Grayson Co.	sh.	ra. li.					x	
	Samples 24–48 are from Chester formations below top of Vienna ls. in well drilled in 1933 on the Sam. Childers farm in SE. Edmonson Co. They are from the following depths: No. 24: 325–330 ft. Nos. 25–40: at 5-ft. intervals, 365–445 ft. Nos. 41–48: at 5-ft. intervals, 455–500 ft.								
24		ls. dense cryst.	ra. li.						
25		ls. dense cryst.	ra. li.						
26		ls. cryst.	ra. li.						
27		ls. cryst.	ra. li.						
28		ls. cryst.	ra. li.						
29		ls. cryst.	ra. li.						
30		ls. cryst.	med. shade	x		x			
31		ls. dense cryst.	med. shade	x		x			
32		ls. dense cryst.	med. shade	x					
33		ls. dense cryst.	ra. li. dark	x		x			
34		sh., sdy.	dark	x					x
35		sh., sdy.	dark	x					
36		ls., dense sh.	ra. li.				x		
37		ls. sdy. cryst.	ra. li. dark				x		x
38		ls. sh. cryst. sdy.	ra. li. dark	xxx	x				
39		ss.	dark	x	xxx	xx			
40		ls. cryst. shaly	dark ra. li.				xx		xx
41		ls. sh. cryst.	dark				x		xx
42–		ls. cryst.	dark				x		xx

TABLE I (*Continued*)
Partial List of Distillation Tests

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
43									
44		ls. cryst. dense	ra. li. dark				x	xx	
45		ls. dense cryst.	ra. li.				x	x	
46		ls. sh. dense cryst.	ra. li.				x		
47		ls. sh. dense cryst.	ra. li.				x	x	
48		ls. sh. dense cryst.	ra. li.				x	xx	
49	49 and 50, uppermost Glen Dean ls.	ls. cryst.	dark				xx		
50	Higdon, Grayson Co.	ls. dense cryst.	dark	xxx			x		
51	Top of Glen Dean ls., NE. Edmonson Co.	ls. cryst.	dark	xxx			x		
52	Glen Dean ls., Grayson Springs, Grayson Co.	ls. cryst.	med. shade					'	
53	Upper Glen Dean or basal Leitchfield, Clarkson, Grayson Co.	sh.	gr. bl.					x	
54	54–56, Glen Dean ls., Higdon	ls. dense cryst.	dark						
55		ls. dense cryst.	dark	x					
56		ls. cryst.	dark						
57	57–61, Vienna ls., S. of Sycamore Branch, Edmonson Co.	ls. dense cryst. shaly	med. shade						
58		ls. dense cryst.	med. shade	x					
59		ls. cryst.	dark						
60		ls. cryst.	dark	x					
61		ls. dense shaly	dark	xxx	x				
62	Leitchfield, Snap, Grayson Co.	sh.	gr. bl.	x				xx	
63	Leitchfield, Higdon	sh.	gr. bl.					x	
64	Leitchfield, Black Rock	sh.	gr. bl.					xxx	
65	Upper Leitchfield, Millwood, Grayson Co.	ls. cryst.	dark						
66	Same as last	ls. cryst.	dark				x	x	
67	Just below base of Vienna ls., Sadler	sh.	gr. gy. dark				x		
68	Top of Leitchfield, Sadler	sh.	gr. bl.						

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
69	Base of Tar Springs form., Grayson Springs	sh.	dark						
70	Leitchfield or Glen Dean, Clarkson	sh.	dark						
71	Glen Dean, Bear Creek, Grayson Co.	ls. dense cryst. shaly	med. shade						
72	Leitchfield, NE. Edmonson son Co.	ls. dense cryst.	med. shade	xx	x				
73–75	Menard ls., N. Logan Co.	ls. dense shaly	ra. li.						
76	Leitchfield, Grayson Co.	sh.	dark				x		
	77–79, upper Chester, SE. of Morganfield								
77		ls. dense cryst. shaly	med. shade						
78–79		ls. cryst.	dark -						
80	Leitchfield, S. Butler Co.	ls. dense shaly	ra. li.						
81	Same as last	sh. limy	gr. gy. med. shade				xxx		
82	Top of Chester series, SE. Hancock Co.	sh.	black	xxx	xx				
83	Base of Leitchfield, SE. Butler Co.	sh.	wh.						
84	Leitchfield form., Hanakers Ferry, N. Warren Co.	sh. sdy.	med. shade						
85	Just below Vienna ls., near Long, Warren Co.	sh.	gr. gy. med. shade						
86	Lower Leitchfield, near Riverside, Warren Co.	sh.	gr. gy. med. shade				xxx		
87	Leitchfield, Hanakers Ferry, Warren Co.	sh.	gr. gy. med. shade				xx		
88	Base of Leitchfield, Long, Warren Co.	sh. limy	wh. gr. gy.				xx		
89	Lower Leitchfield, Riverside, Warren Co.	sh.	gr. gy. med. shade				xxx	x	
90	Leitchfield, Hanakers Ferry, Warren Co.	sh.	gr. gy. dark				xx		
91	Same as last	sh. limy	gr. gy. dark				xx		

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
92	Leitchfield, NE. Warren Co.	sh.	gr. bl.						
93	Leitchfield, Hanakers Ferry, Warren Co.	sh.	gr. gy. med. shade				xxx		
94	Lower Pennsylvanian, Higdon, Ky.	sh.	dark				xx		
	95–97, Lower Pennsylvanian, W. of Caneyville, Ky.								
95–		sh.	gr. bl.	x					
96–		sh.	gr. bl.						
97									
	98–100, basal Pennsylvanian, Sunfish, Ky.								
98		sh.	med. shade						
99– 100		sh.	dark						
101	Lower Pennsylvanian, 3 miles SW. of Caneyville, Ky.	sh.	med. shade						
102	Lower Pennsylvanian, 1 mile S. of Caneyville, Ky.	sh.	gr. bl.						
103	Pennsylvanian, 4 miles SW. of Morganfield, Ky.	sh. limy	med. shade						
104	Same as last	ls. cryst.	gr. bl.					x	
105	Lower Pennsylvanian, S. of Morganfield, Ky.	sh.	dark						
106	Stratum just over Coal No. 11, Morganfield, Ky.	sh. limy	gr. bl.	xxx	xx				
107	Oil sh. which will burn, Lower Pennsylvanian, Caneyville, Ky.	sh.	gr. bl.	xxx	xxx				
	108–114, Lower Pennsylvanian, Threlkel, Ky.								
108– 111		sh.	med. shade						
112		sh.	med. shade				x		
113		sh.	dark				xx		
114		sh.	gr. bl.	x			xx		
115	Lower Chester, Woodrow, Ky.	sh. limy	med. shade						
117									
118	Lower Chester, Breckenridge Co., Ky.	sh.	med. shade						
119	Aux Vases (?) form. (Miss.) near road between Harned	sh.	med. shade						

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
	and Buras, Breckenridge Co.								
120	Same as last	sh.	med. shade				xx		
121	Base of Cypress, Breckenridge Co., Ky.	sh.	med. shade						
122	Lower Chester, Breckenridge Co., Ky.	sh.	dark	x					
123	Same as last	ls. cryst.	dark				xx		xx
124	Chester series, Breckenridge Co., Ky.	ls. dense cryst.	dark	xxx	x				
	125–127, Menard ls. (U. Miss.), NW. Logan Co., Ky.								
125–126		ls. dense	dark	xxx	x				
127		ls. dense shaly	dark	xxx	xxx				
128	Just above Cypress ss., E. Todd Co., Ky.	sh.	dark						
129	Same as last	sh.	gr. bl.						
	130–132, top of Tyrone ls. (Ordovician), Frankfort, Ky.								
130–131		ls. dense	dark	xxx	xx				
132		ls. dense	dark	xxx	xx				
	133–139, Trenton ls. (Ordovician), Bourbon Co., Ky.								
133		ls. dense, shaly	gr. gy. ra. li.	xx					
134–136		sh. limy	gr. gy. med. shade						
137		sh. limy	gr. gy. med. shade					x	
138		ls. dense shaly	gr. gy. ra. li.	xx					
139		ls. dense cryst. shaly	gr. gy. dark						
	140–146, Maysville and Richmond (Ordovician), Lincoln Co., Ky.								

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
140– 142		ls. dense shaly	gr. gy. ra. li.						
143		ls. dense cryst.	dark	xx					
144		ls. dense	dark	xx					
145		ls. dense	dark	xxx	xx				
146		ls. dense	ra. li.						
147– 151	Tyrone ls. (Ordovician), Kentucky River, S. of Lexington, Ky.	ls. dense	ra. li.						
152	Cynthiana ls. (Ordovician), Bourbon County, Ky.	ls. dense cryst. shaly	med. shade	xx	x	x			
153	Tyrone ls. (Ordovician), S. of Winchester, Ky.	ls. dense	ra. li.						
154	Cynthiana ls. (Ordovician), Bourbon Co., Ky.	ls. dense cryst.	dark	xxx	x				
155	Upper Ordovician ls., NW. Clinton Co., about 20 ft. below Chattanooga sh. May contain oil in pores	ls. sdy. cryst	ra. li.	xx	x				
	156–158, Ordovician, N. Robertson Co., Tenn.								
156		ls. dense	gr. bl.						x
157– 158		ls. dense	dark						
159– 160	Base of St. Louis ls., N. Hart Co., Ky.	sh. limy	gr. bl.	xxx	xxx				
161	Silurian sh., near Needmore, Ky.	sh.	gr. gy. ra. li.						
162	Lower Pennsylvanian, Union Co., Ky.	sh. limy	gr. gy. ra. li.						
163	Base of Cypress form., (U. Mississippian), Pauline, Logan Co., Ky.	sh.	dark				xx		
	164–166, Silurian sh., 10 miles E. of Richmond, Ky.								
164		sh. limy	gr. gy. med. shade						
165		sh.	gr. gy. ra. li.				xx		
166		sh.	gr. gy. ra. li.				x		
167	Eden sh. (Ordovician), Carroll Co., Ky.	sh.	gr. gy. ra. li.						
168	50 ft. below base of St. Louis	sh.	gr. gy.						

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
	ls. (Mississippian), Powell Co., Ky.		med. shade						
169	Base of St. Louis ls. (Mississippian), E. Hardin Co., Ky.	ls. dense	dark				x		
170	Upper Warsaw (Mississippian), E. Hardin Co., Ky.	sh. limy	dark	xxx	xx				
171	Mississippian sh. just above Chattanooga sh., Needmore, Ky.	sh.	gr. gy. med. shade						
172	Pennsylvanian, Paintsville, Ky.	sh.	dark	xx					
173	Sh. in black Chattanooga sh., Pamola, Ky.	sh.	ra. li.					xx	
	174–187, Mississippian from Crab Orchard Mts., Tenn.								
174		sh. limy	med. shade						
175		ls. dense cryst. shaly	ra. li.					xx	
176		ls. dense cryst. shaly	dark	x					
177		ls. dense cryst. shaly	dark						
178		ls. dense	ra. li.						
179		ls. dense shaly	wh.	x				xx	
180		ls. dense shaly	ra. li.	xx					
181–182		ls. dense	ra. li.						
183		ls. dense shaly	wh.	xx					
184		ls. dense cryst. shaly	dark	xx					x
185		ls. dense shaly	dark	xxx	x				
186–187		sh. limy	dark	xxx	x				
188	Basal Pennsylvanian sh., Frenchburg, Ky.	sh.	gr. bl.					xx	
189	Mississippian from depth of 1,020–1,026 ft., in well on Elvis Bearow farm, W. of	ls. dense	gr. bl.	xxx					

TABLE I (*Continued*)
PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
190	Bucksville, Logan Co., Ky. St. Louis ls., 2 miles N. of Sunnybrook, Wayne Co., Ky.	ls. dense shaly	wh.						
191	St. Louis ls., Shearer Valley, Wayne Co., Ky.	ls. dense	ra. li.				x		
192	Large concretion of impure ls. in Pennsylvanian, 4 miles N. of Cannel City, Ky.	ls. dense sdy.	dark	x					
193	Mississippian ls. just above Chattanooga sh., Clinton Co., Ky.	ls. cryst.	ra. li.					xxx	
194	Mississippian ls., 50 feet above Chattanooga sh., Illwill Creek, Clinton Co., Ky.	ls. dense	gr. bl.	xxx	x				
195	Pennsylvanian ls. just above thin coal, 4 miles N. of Cannel City, Ky.	ls. dense	gr. bl.	xxx	xxx				
196	Mississippian ls., 75 ft. above Chattanooga sh., Illwill Creek, Clinton Co., Ky.	ls. cryst.	dark	xxx	x				
197	Lower Mississippian, Osco, Clinton Co., Ky.	ls. dense shaly silty	dark	xxx	x			.	
198	Near base of St. Louis ls. (Mississippian), Clinton Co., Ky.	ls. sdy. dense shaly	dark	x					
199	Mississippian, 200 ft. above Chattanooga sh., SW. Rowan Co., Ky.	sh.	med. shade					xx	
200	Mississippian ls., 200 ft. above Chattanooga sh., Handecock Creek, Clinton Co., Ky.	sh. limy	dark						
201	Mississippian sh., 50 ft. above Chattanooga sh., Browns Fork, Clinton Co., Ky.	sh. limy	gr. bl.	x					
202	Sh. just below Chattanooga sh., Browns Fork, Clinton Co., Ky.	sh.	dark					xxx	
203	Sh. at base of Chattanooga sh., Indian Creek, Clinton Co., Ky.	sh.	dark	x				x	
204	Mississippian sh., 50 ft. above Chattanooga sh., Indian Creek, Clinton Co., Ky.	sh.	gr. gy. dark						
205	Sh. at horizon of Cypress ss. (U. Mississippian), SE. of	sh.	ra. li.						

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
	Monticello, Wayne Co., Ky.								
206	Mississippian sh. just above Chattanooga sh., NW. Clinton Co., Ky.	sh.	gr. gy. med. shade				xxx		
207	Mississippian sh., o-3 ft. above Chattanooga sh., NE. Clinton Co., Ky.	sh.	gr. gy. med. shade						
208	Mississippian sh. just above Chattanooga sh., NW. Clinton Co., Ky.	sh.	gr. gy. med. shade				xx		
209	Mississippian sh. just above horizon of Cypress ss., Pilot Mtn., W. of Monticello, Wayne Co., Ky.	sh.	gr. gy. ra. li.				x		
210	Lower Pennsylvanian sh., Isonville, Elliott Co., Ky.	sh. sdy.	dark	x					
211	Lower Pennsylvanian sh., E. of Sandy Hook, Elliott Co., Ky.	sh. sdy.	gr. bl.	x					
212	Lower Pennsylvanian sh., 1 mile S. of Tabor Hill, Elliott Co., Ky.	sh. sdy.	gr. bl.	x					
213	Pennsylvanian ls., 4 miles N. of Cannel City, Ky.	ls. dense	dark						
214	Same as 212	sh. sdy.	gr. bl.	x					
215	Basal St. Louis ls. (Mississippian), Nora, Clinton Co., Ky.	ls. cryst.	dark			x			
	216–218, Warsaw (Mississippian), W. of Monticello, Wayne Co., Ky.								
216		sh. limy	med. shade					xx	
217		ls. dense shaly	gr. bl.				xx	xx	
218		sh. limy	dark						
	219–224 are St. Genevieve and possibly Renault-Paint Creek formations (Mississippian) from following depths in well on J. Bamberry Higdon farm, E. of Grayson Springs, Grayson Co., Ky.:								
	219: 175–180 ft.								
	220: 180–185 ft.								
	221: 200–210 ft.								

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

Odor of Oil	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
	222: 210–220 ft. 223: 220–230 ft. 224: 230–240 ft.								
219–		ls. dense cryst.	wh.						
222									
223–		ls. cryst.	ra. li.						
224									
225	St. Louis ls. (Mississippian), Sunnybrook, Wayne Co., Ky.	ls. dense	wh.						
	226–228, Lower St. Louis ls. (Mississippian) 3 miles E. of Albany, Clinton Co., Ky.								
226		ls. dense cryst. shaly	dark	x				x	
227		sh. limy	dark	xx				xxx	
228		sh. limy dark	dark	x					
229	Lower St. Louis ls. (Mississippian), Clinton Co., Ky.	ls. dense	dark			x		,	x
230	Same as last	ls. dense cryst. shaly	ra. li.						
231	Middle St. Louis ls. (Mississippian), Gap Creek, Wayne Co., Ky.	ls. dense shaly	wh.						
232	Same as 229	ls. dense	dark			x			x
233	Base of St. Louis ls., Wayne Co., Ky.	sh. limy	dark	xxx	x				
234	Base of St. Louis ls., Cartright, Clinton Co., Ky.	ls. dense shaly	med. shade	xxx	x	xx			xxx
235	Black Band iron ore over Coal No. 11 or 12 (Pennsylvanian), Tuscarawas Co., Ohio	shaly	black	xx					
	236–238, Lead Creek ls. (Pennsylvanian), Spencer Co., Ind.								
236		ls. dense cryst.	dark						
237		ls. dense	gr. bl.	xxx					
238		ls. dense	gr. bl.	xxx	x				
239	Martinsburg sh. (Ordovician), Shenandoah Valley, Va.	sh.	black						

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
240	Chattanooga sh. (Mississippian?) equivalent, central Va.	sh.	black						
241	Same as last	sh.	black	x					
242	Ls. associated with Coal No. 6 (Pennsylvanian), Tuscarawas Co., Ohio	ls. dense	black	xx	x				
	243–247, Salem ls. (Mississippian), near Bedford, Ind.								
243		ls. cryst.	med. shade						
244		ls. cryst. earthy	ra. li.			x			
245–246		ls. dense	ra. li.						
247		ls. dense	ra. li.			x			
248	Black band iron ore over Coal No. 6 (Pennsylvanian), Tuscarawas Co., Ohio	shaly	black	xxx	xxx				
	249–252, Warsaw and St. Louis formations (Mississippian), near Keltner, Ky.								
249		ls. dense	med. shade			x			
250		ls. dense	dark	xxx	x				
251		ls. cryst.	gr. bl.	x					xx
252		ls. dense	gr. bl.	xx				xxx	
	Samples 253–443, west Tex. 253–256, Upper Cretaceous sh., Van Horn Canyon								
253–254		sh.	wh.						
255–256		sh. limy	wh.						
	257–262, Cretaceous, just N. of Pinto Canyon, Presidio Co.								
257–258		ls.	ra. li.						
259–262		ls.	med. shade						
	263–266, Permian, Pinto Canyon, Presidio Co.								
263–264		sh.	black	xxx	xx				
265–		ls.	black	xxx	xx				

TABLE I (*Continued*)
PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
266									
	267–271, sh., Hess and Wolfcamp formations, Brewster Co.								
267–		sh.							
269									
270–		sh.	gr. gy.				xx		
271									
272–	Base of Leonard form., W. of	ls.	gr. bl.	xxx	xx				
273	Leonard								
274–	Word form., SW. of Marathon, Brewster Co.	sh.	black	xxx	xx				
275	276–281, lower Word form., 5 miles NE. of Lennox								
276–		sh.	med. shade						
278									
279–		ls.	dark						
281									
	282–306, Word form., W. of Marathon, Brewster Co.								
282		sh. sdy.	med. shade						.
283–		sh.	med. shade	xx					
284									
285–		sh.	med. shade						
295									
296–		sh.			x				
299									
300–		sh.							
306									
	307–321, Pennsylvanian, where Boquillas road crosses Santiago range								
307–		ls.	ra.li						
311									
312–		sh.	gr. gy.						
316									
317–		sh.	black					x	
319									
320–		ls.	dark					x	
321									
322–	Upper Cretaceous, Santiago	ls.	black	xx					
323	Range, S. of Dog Canyon								
	324–331, middle and upper Word, Altuda Mtn. uplift, near Marathon, Brewster Co.								
324–		sh.	med.						

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
327			shade						
328		sh.	med.				x		
330			shade						
331		sh.	med.	x					
			shade						
	332–337, basal Word, 4–5 miles E.-NE. of Lennox								
332–		ls.	gr. bl.						
334									
335–		ls.	gr. bl.	xxx	x				
337									
338–	Lower Cretaceous, W. side of Solitario uplift	ls.	dark	x					
339									
	340–344, Paleozoic, W. side of Solitario uplift								
340–		sh.	black				xx		
342									
343–		ls.	black				xx		
344									
345	Eagle Ford (Cretaceous), W. side of Solitario uplift	sh.	ra. li.	xxx	xx				
	346–353, Lower Cretaceous, 2–3 miles NW. of Shafter, Presidio Co.								
346–		sh.	dark						
348									
349		sh.	dark	xx					
350–		ls.	dark						
351									
352–		ls.	dark	xx					
353									
	354–360. Outcrops of Delaware ls., 31–32 miles from Van Horn and 2 miles S. of divide								
354–		ls.	dark						
357									
358–		ls.	gr. bl.						
359									
360		ls.	gr. bl.	xxx	xx				
	361–415, basal black ls., W. edge of Delaware Mts.								
361–		ls. cryst.	black						
374									
375–		ls. cryst.	black	xx					
410									

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
411–415		ls. cryst.	black	xxx	x				
	416–422, lower part of Hueco ls. exposure in Apache Canyon 35 miles N. of Van Horn								
416–419		ls. dense	dark						
420		ls. dense	dark	x					
421									
422		ls. dense	dark					x	
423	Delaware form., in road about	sh.	dark	x					
424	3 miles S. of Guadaloupe Point								
	425–429, Delaware form., Block 68, Culberson Co.								
425–426		ls.	ra. li.						
427		sh.	ra. li.						
428		sh.	dark	x					
429		ls.	dark	x					
430	Shaly gypsum, Castile (Permian), about 25 miles E. and 4 miles S. of Guadaloupe Point	shaly	dark	x				'	xxx
431		–							
432	Same as last	shaly	dark						xxx
433–435	Probably lower Hueco ls., or possibly older form., near NE. portion of Diablo Mts. and about 5 miles NW. of Figure 2 Ranch	ls.	dark	xxx	xx				
436–438	Hueco ls., same locality as last	ls. dense	gr. bl.	xx					
439–441	Same as last	ls. denes	gr. bl.	xxx	x				
	442–443, black shale and interbedded ls., which lie below Hueco ls. and may be of Devonian age, just north of Diablo Mts.								
442		sh.	black	xxx	xxx				
443		ls.	black	xxx	xx				
444–446	Near mouth of Bone Spring Canyon	ls.	gr. bl.	xxx	x				
	Samples 444–487 are from SE. and S. New Mexico								

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
447	Magdalena ls., Caballos Mts.	ls.	dark						
448	Probably upper Magdalena, same locality	ls.	med. shade	x					
449	Same as last	ls.	dark	x					
450–453	Indurated sh., Caballos Mts. Lies on ss. which lies on pre-Cambrian schists	sh.	gr. gy. med. shade					x	
454–461	Magdalena form., W. side of Organ Mts., 4 miles N. of Organ	ls.	dark						
462–468	Same as last	ls.	black						
469–474	Magdalena form. in gap, 10 miles N.of Organ	ls.	dark						
475–480	Same as last	ls.	black						
481–483	Sh., possibly Percha (Devonian), below Magdalena ls. at same locality	sh.	med. - shade gr. gy.						
484	Same as last	sh.	gr. gy. gr. bl.						
485–487	Just below last at same locality	ls.	dark						
488	Ls., Newark series (Triassic), between Middle and Lower basalt flows, near Northford, Conn.	ls. dense	br. bl.	xxx	xx				
489	Sh. just above Muddy oil sand (Cretaceous), near Wellington, Colo.	sh.	dark						
490	Same as last. Carbonaceous and yields slight tarry odor in closed tube	sh.	dark						
491–492	Deadwood form. (Cambrian), Deadwood, S. Dak.	sh.	gr. gy. dark						
493	Middle Morrison (Jurassic or Cretaceous), NE. Black Hills, S. Dak.	sh.	dark	xxx	xx				
494	Same as last	sh.	dark				xx		
495	Basal Morrison, NE. Black Hills, S. Dak.	sh.	dark				xx		
496	Morrison, W. of Wellington, Colo.	sh.	ra. li.						
497–498	Middle Sundance (Jurassic), NE. Black Hills, S. Dak.	sh.	med. shade						
499	Same as last	sh.	med. shade				xx		
500	Upper Sundance, 50 ft. below	sh.	med.						

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
	top, NE. Black Hills, S. Dak.		shade						
501	Upper Sundance, Hot Springs, S. Dak.	sh.	med. shade						
502	Middle Sundance, Hot Springs, S. Dak.	sh.	med. shade						
503	Upper Sundance, W. of Wellington, Colo.	sh.	dark						
504–505	Middle Sundance, Minnekahta, S. Dak.	sh.	ra. li.				x		
506	Lower Sundance, Minnekahta, S. Dak.	sh.	ra. li.			x			
507	Same as last	sh.	ra. li.						
508	Upper Sundance, Spearfish, S. Dak.	sh.	ra. li.						
509	Middle Sundance, 15 miles S. of Douglas, Wyo.	sh.	ra. li.						
510–514	10 miles S. of Douglas, Wyo. Basal upper, middle lower, upper middle, middle upper, and upper lower Sundance	sh.	ra. li.						
	515–517, Mercer and Putnam Hill ls. (Pennsylvanian), Tuscarawas Co., Ohio	–							
515		ls. cryst.	dark						
516		ls. cryst. shaly	dark	x					
517		ls. cryst.	gr. bl.	xxx	x	x			
	518–527, Mississippian ls., Grassy Cove, Cumberland Co., Tenn.								
518		ls. dense	med. shade			x			
519		ls. dense cryst	dark			x			
520		ls. dense shaly	wh.						
521		ls. dense	dark	xx					
522		ls. dense	med. shade						
523		ls. dense	med. shade	xxx	x				
524		ls. dense cryst.	med. shade						
525		ls. cryst.	dark	xxx	x				x
526		ls. dense cryst.	gr. bl.						x

TABLE I (*Continued*)

PARTIAL LIST OF DISTILLATION TESTS

No. of Sample	Formation, Age, Locality	Kind of Rock	Color of Rock	Odor of Oil	Visible Oil	Odor of Scorching	Odor of Ammonia	Sublimates or Sulphur Fumes	Bituminous Odor when Broken
527		ls. cryst.	dark			xx			xxx
	528–531, Chickamaugua ls. (Ordovician), Tolletts Mill, Sequatchie Valley, Tenn.								
528		ls. cryst.	dark			xx			xxx
529		ls. dense cryst.	dark					xx	
530		ls. dense	gr. bl.			xx			
531		ls. dense cryst.	wb.						
	532–536, Ordovician, 0–200 ft. below base of Chattanooga sh., Coffee Co., Tenn.								
532– 533		ls. cryst.	med. shade						
534		ls. cryst.	med. - shade						x
535		ls. cryst.	dark	xxx	x				xxx
536		ls. cryst.	gr. bl.	xx					xxx
	537–545, highly tilted lower Paleozoic from highway near Mohawk and Bulls Gap, E. Tenn.								
537		ls. cryst. shaly	med. shade						
538		ls. dense cryst. shaly	dark						
539		sh. limy	gr. bl.						
540– 542		ls. cryst.	dark						
543– 545		sh. limy	dark						
	546–549, Chickamaugua ls. (Ordovician), NE. end of Sequatchie Valley, Tenn.								
546		ls. dense cryst.	med. shade						
547		ls. dense cryst.	dark						
548		ls. dense	gr. bl.						
549		ls. dense cryst.	gr. bl.					xx	
550	Chattanooga sh. (Devonian or Mississippian). Area of highly tilted rocks near Ringgold, Ga.	sh.	black	xxx	xxx				

NOTES ON ORIGIN OF OIL IN KENTUCKY[1]

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ABSTRACT

The bearing of distillation tests and field evidence on the theory that the Chattanooga shale is the source of the oil in the associated oil pools of Kentucky is discussed. It appears that this shale has generated chiefly gas, rather than oil, although the evidence is by no means conclusive. There are also some reasons for thinking that the oil in the Onondaga limestone of eastern Kentucky originated in a formation below the Chattanooga shale.

INTRODUCTION

In a previous paper[3] the writer described the common types of organic matter detected by closed-tube tests, and the types of rock with which they are commonly associated. In the course of this investigation some data were accumulated which, considered in connection with the field relations, have a bearing on problems connected with the origin of oil in Kentucky.

RELATION OF OIL AND GAS PRODUCTION TO CONTENT OF ORGANIC MATTER

The tests made by the writer suggest that there is a marked relation between the amount of organic matter in the various formations, and their content of oil and gas. More or less organic matter is present in the Ordovician strata of central Kentucky above the base of the Trenton limestone, in the Chattanooga shale, in the Mississippian strata below the top of the lower dark portion of the St. Louis limestone in western, southern, and southeastern Kentucky, and in the Chester series of western Kentucky. Much oil has been produced from suitable reservoir rocks in, or associated with, these strata. On the other hand, the rocks between the middle portion of the St. Louis limestone and the base of the Chester in western Kentucky contain little or no organic matter, and these rocks have produced no oil in the region adjacent to the area in which the samples were obtained, although suitable reservoir rocks and structures are present.

[1] Manuscript received, August 17, 1933; revised manuscript, April 11, 1934.

[2] 430 Temple Street.

[3] William L. Russell, "Some Characteristics of Organic Content of Rocks," this *Bulletin*, pp. 1103-25.

SIGNIFICANCE OF GAS PRODUCTION FROM CHATTANOOGA SHALE

The Chattanooga shale of Kentucky is a richly bituminous rock which everywhere yields considerable oil and gas on distillation. It ranges from 20 to about 600 feet in thickness. Because of its bituminous nature it has been considered an ideal source rock for oil, and geologists have generally supposed that the oil in the closely associated strata has originated in it. The field evidence, however, casts doubt on the validity of this theory. The gas production from the Chattanooga shale suggests that it has generated gas rather than oil. Hundreds of wells in Kentucky, Tennessee, and adjacent parts of West Virginia and Indiana have found gas or gas showings in the Chattanooga shale, but oil production and oil showings in it are very rare. The only oil production from the Chattanooga shale of Kentucky, as far as the writer could ascertain, is in the Electra pool of Barren County, where oil is produced from it in several wells very close to a fault. As the main production in the Electra pool is found only 40–50 feet below the Chattanooga shale, the oil may have risen through the fault to the shale from the main producing horizon.

It does not appear likely that oil generated with the gas in the Chattanooga shale could in so many places have drained away to lower horizons. Though in some places the shale is underlain by a porous reservoir, in many regions it is underlain by shales or limestones which give no indication of being porous and pervious. In eastern Kentucky, where there is considerable gas production from the Chattanooga shale, and where gas showings in it are very common, it is generally underlain by a bed of light gray or white shale. If large volumes of oil had been formed in the Chattanooga shale, it would seem that at least some of this oil would have been unable to settle through the impervious rocks on which the shale rests, and would be encountered in the same pores or crevices in which the gas is found. It is also very unlikely that large quantities of oil have originated in this shale and escaped into the overlying formations. In eastern Kentucky it is overlain by a thick series of rather soft shales which would tend to impede the migration of oil in that direction. If oil and gas were originally present in the Chattanooga shale, it is likely that the gas, being lighter and more mobile than the oil, would tend to leave the oil behind in migrating upward. Since water is rarely encountered in the shale, the oil could probably not have been floated out of the shale by virtue of its buoyancy in water. These considerations suggest that the Chattanooga shale has generated gas but little or no oil.

SOURCE OF OIL IN ONONDAGA LIMESTONE OF EASTERN KENTUCKY

In eastern Kentucky, where oil production is obtained from the Onondaga limestone in considerable areas, the stratigraphic section is as follows. Above the Chattanooga shale there is 450–650 feet of greenish and bluish gray shale of Mississippian age. The Chattanooga shale itself is 100–200 feet thick, and at its base there is a layer of grayish or white shale 1–30 feet thick. Beneath this is the Onondaga limestone of Devonian age, called "Corniferous" by the oil operators. It varies from a few feet to more than 150 feet in thickness. It is crystalline, dolomitic limestone, in part very porous, and in places containing quartz sand. Beneath it is a series of bluish, greenish, and reddish shales of Silurian age which is about 100 feet thick. At the base of the Silurian there is a thin, crystalline, dolomitic limestone, which in its outcrops is moderately porous in places, and which is known as the Brassfield limestone. Beneath this there is a series of limestones, calcareous shales, and shales of Ordovician age which is 800–1,000 feet thick. The outcrops of both the Onondaga limestone and the Brassfield limestone are in places impregnated with dried oil.

In the Big Sinking pool, of Lee County, oil is derived from three "pays" in the Onondaga limestone. Salt water is found in the Onondaga limestone down the dip, and it is now found in the middle "pay" in the oil pool, although, according to Jones and McFarlan,[4] it was not generally present when the field was first drilled. As Jones and McFarlan[5] point out, the variations in the thickness of the Onondaga limestone bring the Chattanooga shale into contact with each of the three "pays" in the general region of the oil pool. There are, however, some reasons for thinking that the oil may have originated in the rocks beneath the Chattanooga shale. According to Jones and McFarlan,[6] the two upper "pays" in the region of the oil pool contain considerable salt water, while only oil has been found in the lower "pay." The fact that the two upper "pays" are only partly filled with oil, while the lower "pay" was completely filled with it, is rather suggestive of a source from below. While it is true that the thinning of the Onondaga limestone in places brings the Chattanooga shale in contact with the lower "pays," in certain areas, these areas, as the isopach map of Jones and McFarlan[7] shows, are all up the dip. Hence,

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[4] D. J. Jones and A. C. McFarlan, "Geology of the Big Sinking Pool, Lee County, Kentucky," *Kentucky Bur. Min. and Top. Survey Bull. 1* (1933), Pl. VI.

[5] *Op. cit.*, p. 4 and Pl. I.

[6] *Op. cit.*, p. 7.

[7] *Op. cit.*, Pl. I.

if oil entered the lower "pays" in these areas, it would have to move down the dip for some distance. Since the producing formation contains salt water down the dip, one would expect that the oil would migrate up the dip toward the west, instead of descending in the opposite direction. If the oil reached the Onondaga limestone from the Chattanooga shale, it is to be expected that it would enter it in the region down the dip. Not only is this the area from which the oil would be likely to migrate by virtue of its buoyancy, but this area down the dip is much more extensive than the area in which the Chattanooga shale is in contact with the two lower "pays" (except for the intervening gray shale). But if the oil entered the formation down the dip, it would be found chiefly or entirely in the upper "pay," since it is scarcely likely that it would migrate downward through a water-bearing horizon. The fact that the Brassfield limestone is petroliferous in its outcrops, and the fact that showings of oil are found in this region in a limestone about 100 feet below the base of the Onondaga limestone, suggest that there is a source of oil in the lower formations.

The three possible sources beneath the Chattanooga shale are the Onondaga limestone itself, the Silurian shales, and the Ordovician shales and limestones. While some of the oil may have originated in the Onondaga limestone, it is doubtful if it contained enough organic matter to form the large quantities of oil that have been found in it. The writer was not able to obtain samples of the Silurian and Upper Ordovician rocks in the oil field, but a few samples of these rocks from their outcrops to the west were tested in the closed tube. It was found that some of the Silurian shales gave an odor of ammonia when distilled, although none of them was bituminous. Some of the Upper Ordovician shales also yielded an odor of ammonia, and some of the shales and limestones were bituminous. As the Silurian shales were directly beneath the producing formation, it is possible that the oil was generated from the organic matter which produces the odor of ammonia when distilled. If the oil originated in the bituminous matter in the Ordovician strata, it would have to traverse a series of shales and thin limestones at least 100 feet thick in order to reach the producing horizon. However, it is certain that water is forced through considerable thicknesses of shales as they are compacted by the weight of the overlying sediments, and if oil were present it would presumably also be forced through the same thicknesses of shale during compaction.

SOURCE OF OIL ASSOCIATED WITH CHATTANOOGA SHALE IN SOUTHEASTERN KENTUCKY

In southeastern Kentucky oil has been found in several horizons which are more or less closely associated with the Chattanooga shale. In Cumberland, Monroe, Clinton, Wayne, and Russell counties, oil has been found in Ordovician limestones from 250 to 600 feet below the Chattanooga shale, called "Sunnybrook sands" by the oil operators. In some of these oil pools there is a horizon which contains salt water even on anticlines, and which lies just above the "Sunnybrook sand," and about 200–250 feet below the Chattanooga shale. The unconformity beneath the Chattanooga shale in this region nowhere brings the "Sunnybrook" oil-bearing strata into contact with it. These relations indicate that the oil in the "Sunnybrook" horizons did not originate in the Chattanooga shale.

The evidence regarding the source of the oil in the Mississippian rocks of this region is much less conclusive. The Chattanooga shale is generally 25–40 feet thick, and at its base there is locally a bed of grayish shale a few feet thick which in places yields ammonia on distillation. The Mississippian strata in the 300–350-foot interval between the Chattanooga shale and the base of the St. Louis limestone consist of dark calcareous shales with beds of limestone and some greenish shales at the base. Some of the greenish shales yield an odor of ammonia in the closed tube, some of the calcareous shales yield traces of oil, and some of the limestones yield traces of oil or an odor of scorching. In a belt between McCreary and Grayson counties, Kentucky, there are local deposits of lenticular limestone or dolomite that is in places porous and pervious, and which is called "Beaver sand" by the oil operators. It lies 1–100 feet above the Chattanooga shale. West of the Cincinnati anticline the production from this horizon has been almost entirely gas, but in Wayne and McCreary counties it has produced considerable oil and some gas, and some oil operators say that the best oil production is found where it lies very close to the Chattanooga shale. The close association of this formation with the Chattanooga shale suggests that the oil in it came from this shale. However, the greenish shales which yield ammonia on distillation are extensively developed at this horizon and it is also possible that the oil originated in them, or in the other types of organic matter in the rocks above the Chattanooga shale. The same statement applies to the oil found in the "Stray sand" of this region, a horizon lying about 150–200 feet above the Chattanooga shale.

The evidence suggesting that the asphalt in the Chester series of

western Kentucky has originated from shales yielding ammonia on distillation has been discussed by the writer[8] elsewhere.

CONCLUSIONS

1. In Kentucky the horizons yielding oil and gas are generally associated with formations containing organic matter, and horizons associated only with rocks devoid of organic matter have yielded little or no oil.

2. The Chattanooga shale has probably been the source of the gas found in it, but there is no conclusive evidence to show that it has been the source of the oil in the associated formations.

3. Although the evidence is far from definite, it seems likely that the oil in the Onondaga limestone of eastern Kentucky originated in a formation beneath the Chattanooga shale.

[8] William L. Russell, "Origin of the Asphalt Deposits of Western Kentucky," *Econ. Geol.*, Vol. 27, No. 6 (September–October, 1933), pp. 571–86.

OSAGE FORMATIONS OF SOUTHERN OZARK REGION,[1] MISSOURI, ARKANSAS, AND OKLAHOMA

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ABSTRACT

On the south and southwest flanks of the Ozark dome the middle Mississippian Osage group, where fully represented, comprises, from bottom to top, the St. Joe, the Reeds Spring (in part the Grand Falls chert), the Burlington, the Keokuk, and the Warsaw formations. Heretofore these formations in this area have been collectively referred to the "Boone formation," but it is clear that the term "Boone" should be suppressed as a synonym of the term "Osage." A green shale which crops out at the base of the group and which several previous writers have called Kinderhook is definitely shown to be Osage. The Reeds Spring formation occurs in Arkansas, and it forms a large part of the Osage as that group is exposed in Oklahoma. Lower Burlington limestone is recorded from Oklahoma and is correlated with strata in Arkansas, and the chert in Oklahoma that has previously been called Keokuk and Warsaw is believed to be largely Burlington in age. Chert in the vicinity of Batesville, Arkansas, which Girty believes to be of Warsaw age, should not be referred to the Osage group. Evidence indicates that the lower Caney shale of the Arbuckle Mountain region is not the clastic equivalent of the Osage group, as some geologists now hold.

In the southern Ozarks of Missouri, Arkansas, and Oklahoma the Osage formations contain so much chert and are so difficult to differentiate on a lithologic basis that they have been lumped together and collectively referred to the "Boone formation" or the "Boone chert." However, this group, where fully represented, consists of at least five fossiliferous marine formations: the St. Joe, the Reeds Spring (in part the Grand Falls chert), the Burlington, the Keokuk, and the Warsaw. The calculated thickness of the group aggregates over 400 feet, but the thickness of the best exposures is in most places nearer 300 feet. Purdue and Miser (1916, p. 10)[3] found that as the Osage is traced southward in the Harrison Quadrangle in Arkansas it thickens from 300 to 400 feet. In Oklahoma, because of an erosional unconformity, the group is only about 35 feet thick at its southernmost outcrop just before it dips under younger Mississippian formations. Where the Osage is typically developed in this area there is a relatively thin pure limestone at the base, and the overlying beds are made up largely of alternating limestone and chert. Locally there are some very pure limestone lenses, but considerable variation, both laterally and

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[3] Parenthetical references indicate Bibliography at end of this article.

vertically, in the amount of chert present has been one of the two chief difficulties encountered in tracing the individual formations even for short distances.

With the exception of the Reeds Spring formation and the Grand Falls chert, all of the Osage formations are highly fossiliferous, but the fossils represent only internal and external molds in instances where they are preserved in chert and this makes specific comparisons difficult. The Osage formations in the type sections in southeastern Iowa and the adjacent part of Illinois are well known, and through the comparatively recent work of Weller, Van Tuyl, and Moore the stratigraphic range of the fossils occurring in this group is known. It is significant that the Osage in the Upper Mississippi Valley has been subdivided partly on the basis of its crinoid remains; brachiopods have been included in fossil lists but no serious attempt was made to establish their exact vertical range until Weller prepared a monograph of the Mississippian brachiopods in 1914. Weller had access to the James Hall, Gurley, Sampson, Rowley, Greger, and other collections, in addition to material in the United States National Museum, and although these collections contained Mississippian brachiopods from many localities, the stratigraphic range of the brachiopods still is not as well known as is that of the crinoids. It is difficult to correlate Osage formations with the type sections in the absence of crinoids and crinoids are exceedingly rare in the southern Ozarks.

L. R. Laudon called the writer's attention to the problem of the "Boone chert" in the fall of 1930, and during the following 2 years most week-ends were spent in the field studying outcrops and collecting fossils zone by zone. Much of the school year of 1931–32 was spent in the laboratory in the preparation and identification of these fossils.

During the summer of 1932 the writer studied the standard Osage sections of the Mississippi Valley, and during the field season of 1933 equivalent sections in Indiana, Kentucky, and Tennessee were visited. Specific comparisons of the fossils obtained were made with Mississippian fossils in the collections at the University of Tulsa, and with those at the State University of Iowa, which includes the large Van Tuyl collection.

In addition to calling attention to this problem Doctor Laudon has materially aided the writer in obtaining the information from which this paper has been prepared; most of the field work was done under his supervision, he frequently accompanied the writer in the field, and concurs with him in most of the premises and conclusions presented in this paper. The writer is indebted to L. A. Johnston of the Sinclair Oil Company for information pertaining to the subsurface

distribution of the Osage in Oklahoma and to F. A. Bush of that company for permission to publish part of one of their well logs. A. K. Miller of the State University of Iowa has supervised the preparation of the manuscript, and A. C. Trowbridge has offered many friendly criticisms.

<div align="center">PREVIOUS WORK</div>

In order to keep this paper within reasonable limits only the salient points of the most important papers dealing with the southern Osage ("Boone") will be considered.

The term "Boone" was first introduced into geologic literature in 1891 by Simonds (pp. 27–37, 149) and by Penrose (pp. 129–138), although J. C. Branner was the nomenclator and previously used it orally. Branner gave the name "Boone" to these Osage beds because they are well developed in Boone County, Arkansas, but he did not list type sections. The term "Boone formation" has since been used by the United States Geological Survey in a formation sense, but because the "Boone formation" clearly is to be correlated with the Osage of the Upper Mississippi Valley, the term "Boone" should be suppressed as a synonym of "Osage," a term which clearly has priority.

In 1905 Taff (p. 3) recognized the "Boone formation" in Oklahoma and correctly correlated the non-cherty limestone at its base with the St. Joe limestone of Arkansas. Two years later Siebenthal (1907a) divided the "Boone formation" of southwestern Missouri into five members: (1) a lower chert and limestone member (unnamed), overlain by (2) the Grand Falls chert, (3) a middle limestone member (unnamed), (4) the Short Creek oölite, and (5) an upper limestone member (unnamed); the Burlington-Keokuk division line was drawn at the base of the Grand Falls chert, and the Short Creek oölite was placed at the base of the Warsaw. In a later paper published the same year (1907b, p. 190) Siebenthal recognized the Short Creek in Oklahoma.

Weller in 1909 (pp. 265–332) correlated the Fern Glen formation of southeastern Missouri with the highest "non-typical Chouteau" (Sedalia of Moore); those rocks in northern Arkansas which stratigraphically occur immediately subjacent to the typical "St. Joe marble" he believed to be the equivalent of the Fern Glen.

In a collection of "Boone" fossils which he had obtained a few miles east of Pryor Creek, Oklahoma, Snider (1914, p. 617) identified *Productus [Dictyoclostus] setigerus*, *Spirifer logani*, and *Derbya [Orthotetes] keokuk*, and he stated that this fauna was indicative of Keokuk age.

After a study of about 40 fossil collections from the "Boone" of Boone County, Arkansas, Girty (1915a, p. 1) ventured the opinion that the "Boone" in Boone County contains beds ranging from Fern Glen to Keokuk in age, that there are no sharp faunal breaks within the "Boone," and he called attention to the fact that the "Boone" faunas are facies faunas which differ in many respects from those of the type sections of the Osage. Girty expressed doubt that any considerable part of the "Boone" of the Joplin district is younger than typical "Boone." He favored a Keokuk age for the "*Productus magnus*" fauna of this district, and evidence was presented to show that the "Spring Creek" limestone member of the Moorefield shale from near Batesville, Arkansas, should be classed with the underlying chert, which had been regarded as the upper member of the "Boone" of this area, and although Girty stated that this chert "member" was probably younger than Keokuk, he did not dismiss the possibility that it was a "remarkable" chert variant of the "Boone formation." In a later paper published in the same year (1915b) Girty described a fauna which was collected a few feet above the "lithologic top of the St. Joe" limestone at St. Joe, Arkansas, and determined the fauna to be Burlington in age. He followed Weller in correlating the lower St. Joe with the Fern Glen, but he stated that the Fern Glen fauna is an Osage rather than a Kinderhook assemblage. Girty had by this time changed his opinion with respect to the "*Productus magnus*" fauna of the Joplin district and agreed with Weller that it is Warsaw rather than Keokuk in age.

In 1916 Purdue and Miser in referring to the "Boone formation" of the Eureka Springs-Harrison quadrangles, Arkansas, which together have approximately the same boundaries as Boone County, stated that it comprises strata which range from Kinderhook to Warsaw in age, and correlated an oölitic limestone which occurs in these quadrangles with the Short Creek oölite.

Buchanan (1927, p. 1314) thought that the lower portion of the cherty part of the "Boone" of Oklahoma contains late Burlington fossils and that the more fossiliferous upper part contains a Keokuk and early Warsaw fauna. The argillaceous beds beneath the St. Joe limestone in the Tahlequah Quadrangle he referred to the Kinderhook.

Moore in 1928 proposed the name Sedalia for the beds included in the upper Chouteau of Swallow, and included under the term Reeds Spring some beds in southwestern Missouri which lie between the St. Joe and the Grand Falls chert; he determined these beds to be of lower Burlington age. Moore also called attention to the ab-

sense of upper Burlington strata in extreme southwestern Missouri and noted that the Keokuk rests directly on the Reeds Spring.

Girty's third article concerning the "Boone" of Arkansas appeared in 1928, and in this paper he stated that the fauna of the "middle Boone" near Batesville represents an undifferentiated Burlington and Keokuk assemblage, although he recognized that neither of these facies is represented with full integrity in this vicinity. He concluded after a lengthy review of all available evidence, that the chert "member" which lies between the "middle Boone" and the "Spring Creek" limestones most probably represents an eastward extension of the typical "Boone," the youngest part of which he had come to believe is Warsaw in age.

FIG. 1
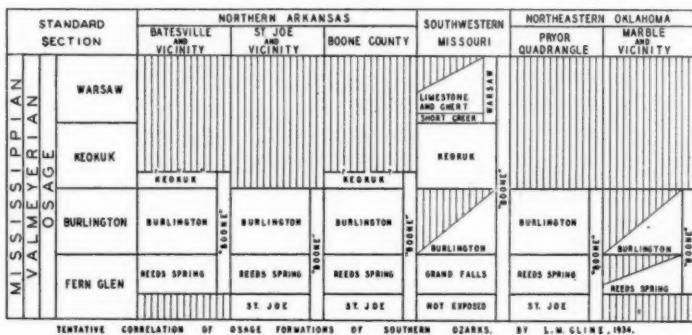
In 1930 three papers appeared which had an important bearing on the age of the "Boone." Ireland referred to the Kinderhook a thin green shale which occurs at the base of the St. Joe in Oklahoma. Croneis questioned the use of the term "Boone" in the sense of a formation, and he expressed the view that certain beds (Reeds Spring) which overlie the St. Joe in Arkansas are also of Fern Glen age. He regarded the evidence that the oölite of north-central Arkansas is of Short Creek age as inconclusive, although he did not question the correlation of certain beds in southwestern Missouri with the Warsaw. Cram stated that certain shale beds outcropping in the Tahlequah Quadrangle, Oklahoma, contain a Fern Glen fauna and are not of Kinderhook age as they had heretofore been regarded. He proposed to restrict the term "Mayes" to beds containing a "Spring Creek" fauna and to include in the Chester the upper part of Snider's "Mayes." Cram doubted the advisability of applying the term "Boone" to beds

containing a "Spring Creek" fauna, in view of the fact that the upper part of the so-called "Boone" of the Batesville district, which contains a "Spring Creek" fauna, has not yet been proved to be true "Boone."

Recently (1933, pp. 203–204) Moore has published an abstract in which he stated that "the Grand Falls chert of the Joplin district appears to be Reeds Spring instead of Keokuk in age." The St. Joe limestone was correlated with the lower non-cherty part of the Fern Glen in the type section. According to him the upper part of the Fern Glen in the vicinity of Fern Glen Station contains units which correspond to the Sedalia and Reeds Spring limestones. The Reeds Spring limestone, which heretofore has been recorded only in southwestern Missouri, is mentioned as being widespread in the Ozarks. Disconformity above the Reeds Spring and a different fauna are said to make possible the differentiation of beds of Fern Glen age from the succeeding Burlington limestone.

ST. JOE FORMATION

The name St. Joe was coined and used orally by Branner, but Hopkins (1898, pp. 150, 253) was the first to use the term in print. Although a type section was not designated, Girty (1915b, p. 25) has made it clear that the type section is at St. Joe, Arkansas, and is probably in a railroad cut on Mill Creek 1.5 miles north of the railroad station. Hopkins (*op. cit.*, p. 254) used the name St. Joe to refer to "that part of the bed of red colored limestone at the base of the Boone chert which is entirely free from chert," and Williams (1892) published lists of fossils from collections that the Arkansas Geological Survey had obtained from this limestone. Because beds subjacent to the "St. Joe marble" are of approximately the same age the writer proposes that the name St. Joe be given formation rank and proposes to regard the red limestone, its lateral equivalents, and the subjacent calcareous shales which carry a Fern Glen fauna, as members of the St. Joe formation.

General character.—At the type section of the St. Joe there is a thin green shale at the base of that formation which contains black phosphatic nodules; fossils have not been recorded from this shale at this locality. In most places where the writer has studied the contact of the St. Joe and the underlying formations there is present a thin green shale at the base of the St. Joe. There are several feet of green shale beneath the typical red St. Joe limestone in a road cut near the post office at Willcockson, Arkansas, from which the writer has collected fossils. The fauna, though small, shows clearly that the

containing beds are of Fern Glen age and they should therefore be
included in the St. Joe formation. The following fossils were obtained
from the shale at this locality.

Poteriocrinus sp (of Weller)	*Spirifer vernonensis* Swallow
Leptaena analoga (Phillips)	*Brachythyris chouteauensis* Weller
Pustula? sp.	*Cliothyridina glenparkensis* Weller
Rhipidomella jerseyensis Weller	*Platyceras paralius* (W. and W.)

With the exception of the brachiopod which is doubtfully re-
ferred to the genus *Pustula*, all of the above listed species occur in
the type section of the Fern Glen at Fern Glen Station near St. Louis,
Missouri.

In Sec. 36, T. 18 N., R. 22 E. and along the Illinois River bluff
in the Tahlequah Quadrangle, Oklahoma, beneath the St. Joe lime-
stone there is a dull blue earthy fossiliferous limestone which Snider
(1915, p. 22) believed to be Kinderhook but which Cram (1930, p.
557) believed to contain a Fern Glen fauna. Cram stated that R. C.
Moore concurred in correlating these beds with the Fern Glen, and
since he (Cram) did not list the fossils that he found from these beds,
the writer is here listing the species occurring in a collection which
L. R. Laudon obtained from near the Eagle's Nest, along the Illinois
River bluff, northeast of Tahlequah, and which he kindly gave the
writer for study.

Cladoconus americanus Weller?	*Rhipidomella oweni* Hall and Clarke
Favosites valmeyerensis Weller	*Schizophoria poststriatula* Weller
Fenestella sp.	*Punctospirifer*, n. sp.
Leptaena analoga (Phillips)	*Brachythyris suborbicularis* (Hall)
Dictyoclostus fernglenensis (Weller)	*Athyris lamellosa* (Lèveillè)
Dictyoclostus? sampsoni (Weller)	*Cliothyridina prouti* (Swallow)
Productella patula Girty	*Platyceras paralius* (W. and W.)

Siebenthal (1907b, p. 190) noted the presence in northeastern
Oklahoma of a green shale between the Chattanooga and the St. Joe
formations and it is doubtless this same shale that Bloesch (1930, p.
361) called Kinderhook. Ireland (1930, p. 486) also referred this bed
to the Kinderhook. What appears to be the same bed of green shale
occurs at the base of the St. Joe southeast of Tahlequah and in Sec.
2, T. 19 N., R. 20 E. in Oklahoma, and at a place one mile north of
Noel, Missouri, on the Neosho highway. That such a thin bed of soft
shale could have undergone the post-Kinderhook and pre-Osage
period of erosion that took place in this area and still be present at
the base of the St. Joe in all outcrops seems unbelievable. This bed,
though probably not of precisely the same age wherever present,
corresponds to the green shale which occurs at the base of the St.
Joe in the type section and it probably represents the reworking of

the tops of older Paleozoic formations by the transgressing Fern Glen sea, and is therefore of Fern Glen age.

The main body of the St. Joe at the type section is composed of about 25 feet of red crinoidal limestone, which occurs in layers that for the most part are less than a foot thick, but on weathered surfaces the formation appears massive. It is more resistant to erosion than the underlying Chattanooga shale and where the contact of the two formations is exposed, as at Noel, Missouri, and in the Tahlequah Quadrangle, Oklahoma, sapping of the St. Joe produces overhanging cliffs. This member of the St. Joe is widespread throughout the southern Ozarks and has an average thickness of from 25 to 40 feet but locally it attains a maximum thickness of about 100 feet. In Boone County, Arkansas, the red limestone facies is well developed but farther west and northwest it is replaced by blue-gray limestone intercalated with thin beds of shale. In Missouri and Oklahoma the limestone in the upper part of the formation becomes less fossiliferous, is lithographic, and breaks with a conchoidal fracture.

Correlation.—The second Arkansas Geological Survey recognized that the fauna of the St. Joe was like that of the Fern Glen of Missouri and the two formations were correlated. Weller (1909, p. 325) correlated only the lower part of the St. Joe with the Fern Glen. After a study of the type section of the St. Joe, Girty (1915b, p. 27) announced that the fossils of the upper St. Joe were similar to those in the lower part, and he correlated all of the formation with the Fern Glen. Moore (1933, p. 203) now thinks that the St. Joe is equivalent to only the lower non-cherty part of the Fern Glen and with this correlation the writer is in accord.

Paleontologic character.—Through the work of Hopkins, Weller, and Girty, the fauna of the St. Joe of Arkansas is well known, and Moore (1928, pp. 163–165) has published a long list of species that occur in that formation in southwestern Missouri. Taff (1905, p. 3) early correlated the St. Joe of Oklahoma with the St. Joe of Arkansas and his correlation has never been seriously questioned. From time to time a few fossils have been listed from the St. Joe of Oklahoma but a complete list of all known species has never been published. In Table I all of the species known from the St. Joe of Oklahoma are listed and the localities from which they came are recorded.

Stratigraphic relations.—In places where the Chattanooga shale is missing the St. Joe rests directly on Ordovician or Silurian formations; in the easternmost outcrops it lies unconformably on the St. Clair (Silurian) limestone. There is a distinct unconformity between the St. Joe and the Chattanooga and in some places the base of the

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TABLE I

FAUNA OF ST. JOE FORMATION OF OKLAHOMA*

	a	b	c	d
Amplexus brevis Weller	×	–	–	–
Cyathaxonia arcuata Weller	×	–	–	×
Cyathaxonia minor Weller	×	–	–	–
Favosites valmeyerensis Weller	–	–	×	–
Cladoconus americanus Weller?	×	–	×	–
Fenestella sp.	–	×	–	–
Platycrinus?	–	×	–	–
Schizoblastus sayi (Shumard)?	–	×	–	–
Cystodictya lineata Ulrich	×	–	–	–
Leptaena analoga (Phillips)	–	×	×	–
Chonetes logani N. & P.	×	–	–	×
Productella patula Girty†	–	–	–	×
Productella concentrica (Hall)	×	×	–	–
Dictyoclostus fernglenensis (Weller)	×	–	×	–
Dictyoclostus? blairi (Miller)	×	–	–	–
Dictyoclostus? sampsoni (Weller)	×	–	×	–
Rhipidomella oweni Hall and Clarke	–	–	×	–
Rhipidomella jerseyensis Weller	–	–	×	×
Rhipidomella diminutiva Weller	–	–	–	×
Schizophoria poststriatula Weller	–	–	×	–
Schizophoria swallovi (Hall)	–	–	–	×
Schizophoria sedaliensis Weller	×	–	–	–
Shumardella? obsolens (Hall)	–	–	–	×
Rhynchopora? rowleyi Weller	×	–	–	–
Punctospirifer, n. sp.	–	–	×	–
Punctospirifer subtexta (White)	–	–	–	×
Punctospirifer subelliptica (McChesney)	×	–	–	–
Spirifer latior Swallow	×	–	–	. –
Spirifer grimesi Hall?	–	×	–	–
Spirifer rowleyi Weller	–	–	×	–
Spirifer vernonensis Swallow	–	–	×	–
Brachythyris peculiaris (Shumard)	×	?	–	–
Brachythyris suborbicularis (Hall)	–	–	×	–
Brachythyris chouteauensis Weller	–	–	×	–
Syringothyris sp.	–	×	–	–
Ptychospira sexplicata (W. & W.)	–	–	–	×
Athyris lamellosa (Lèveillè)	×	–	×	×
Cliothyridina prouti (Swallow)	×	–	×	–
Platyceras paralius (W. and W.)	–	–	×	–

a. Listed by Snider (1915, p. 23) as occurring at Eagle Bluff along Illinois River, Tahlequah Quadrangle, Oklahoma.

b. Approximately the same locality as the last. Listed by Taff (1905, p. 3).

c. Same as above but collected by L. R. Laudon and by the writer.

d. South bank of Spavinaw Creek, a few hundred feet below the dam at Spavinaw, Oklahoma.

* The fossils listed in this paper which were collected by the writer and those collected by Laudon are in the repository at the State University of Iowa, where they are catalogued under the numbers 2324–2599 inclusive.

† In the opinion of the writer the genus *Productella* has been used in such a wide sense that it has come to have little meaning. If the genus were subdivided as it should be, two or more genera would be recognized.

St. Joe contains black phosphatic nodules which undoubtedly were set free from the Chattanooga shale by erosion and were subsequently

incorporated in the St. Joe. Then, too, the distribution of the two formations is not the same. Purdue and Miser (1916, p. 12) have noted that in places in northern Arkansas the St. Joe rests on the Sylamore sandstone, which is the basal member of the Chattanooga formation.

There are local unconformities within the St. Joe but they are of little time value. Snider (1915, p. 23) noted a small angular unconformity in the St. Joe in the Tahlequah Quadrangle, Oklahoma; the truncated shales he called Kinderhook, and the overlying limestone he called St. Joe. As has been stated, these lower shales also contain a Fern Glen fauna, so the unconformity is not large. Moore (1928, in a picture opposite page 104) has recognized that there are rapid changes in dip in the St. Joe near Noel, Missouri, and the writer has visited the St. Joe outcrops in this vicinity and also has noted rapid variations in amount and in direction of dip within the formation. Purdue and Miser (*op. cit.*, p. 11) called attention to an apparent unconformity in the St. Joe near Yardelle, Arkansas, and they would explain this and similar structures as being the result of the submarine erosion; this explanation seems to be adequate, for the fossils show that any break in sedimentation must have been of short duration.

Typically there is a gradual transition from the St. Joe upward into the Reeds Spring formation, but locally, as at two places near Bunch, Oklahoma, where the Reeds Spring rests on Silurian strata, there are evidences of unconformity. The contact of the two formations was drawn by Moore (1928, p. 169) at the lowest chert horizon. The St. Joe and Reeds Spring faunas are similar in many respects, but slightly different assemblages and minor differences in the St. Joe species which range up into the Reeds Spring, together with the abrupt appearance of chert in the latter formation, make differentiation of the two formations possible; it seems best to regard the two as distinct formations even though in many places the line of demarcation is an arbitrary one.

REEDS SPRING FORMATION

Moore (1928, p. 190) recognized that the cherty limestone which overlies the St. Joe in the Missouri Pacific Railroad cut, southeast of Reeds Spring, Missouri, should not be classed with the St. Joe; therefore, he called this formation the Reeds Spring limestone and designated this locality as the type section. East of Crane and west of Grand Falls, Missouri, Moore obtained large collections of fossils from the Reeds Spring and stated that these fossils showed the formation to be older than upper Burlington; although he provisionally

correlated it with the lower Burlington (p. 191) he did not dismiss
the possibility that it might "be in part, or even entirely, slightly
older than the Burlington." Siebenthal (1907a, p. 4) proposed the
name Grand Falls for a prominent chert bed which occurs in the
Osage in the Joplin district in Missouri and which is especially well
developed at Grand Falls on Shoal Creek, 5 miles south of Joplin.
He regarded the chert, which is exposed at the falls and at a locality
one-half mile west of the falls, as distinct from the underlying beds
of alternating chert and limestone, and thought that the Burlington-
Keokuk contact should be drawn at the base of the Grand Falls.
In 1928 when Moore's paper dealing with the Mississippian of Mis-
souri appeared, Moore apparently did not question Siebenthal's age
determination of the Grand Falls, but more recently (1933, p. 203)
he has announced that the Grand Falls appears to be of Reeds Spring
age. In December, 1931, the writer spent two days collecting fossils
from the Reeds Spring at its outcrop just west of Grand Falls and
in studying its relations to the overlying Grand Falls chert; at the
end of that time no definite conclusions were reached. After Moore's
abstract appeared in 1933 the writer again visited this section, this
time in the company of L. R. Laudon, and they both are now of the
opinion that the Grand Falls is only a local chert variant of the upper
Reeds Spring. It is not clear whether the Grand Falls should be con-
sidered as a distinct formation or as only a member of the Reeds
Spring formation, but in view of the recommendation in the recent
report of the Committee on Classification and Nomenclature of Rock
Units (Article 6),[4] it seems best to regard the two as distinct forma-
tions, although it is recognized that they are, in part, of the same age.

Distribution and thickness.—It has been the prevalent opinion
that the Reeds Spring formation occurs only in southwestern Missouri
and in closely adjoining areas, but Moore (1933, p. 203) now recog-
nizes that the formation is widespread around the Ozarks. Purdue
(1907, p. 2) noted in the Winslow (Arkansas-Oklahoma) Quadrangle
that there is, in many places, limestone in the lower part of the
"Boone" that is lithologically similar to the upper St. Joe, and he and
Miser (1916, p. 11) observed that "certain beds which are known by
their fossils to be of Fern Glen age, overlie the typical St. Joe on War
Eagle Creek in the Eureka Springs [Arkansas] quadrangle." The areal
distribution of the Reeds Spring exceeds even that of the persistent
St. Joe formation; it constitutes almost the whole of the Osage as
that group is exposed in the Tahlequah Quadrangle in Oklahoma.

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[4] "Classification and Nomenclature of Rock Units," *Bull. Amer. Assoc. Petrol.
Geol.*, Vol. 17, No. 7 (July, 1933), p. 851.

The Grand Falls chert is recognized only in the Joplin district in Missouri.

Moore (1928, p. 170) determined the thickness of the Reeds Spring in southwestern Missouri to be from 130 to 225 feet. In a bluff on the north side of Spavinaw Creek (Oklahoma), about 2.5 miles upstream from its junction with Grand River, the Reeds Spring formation measures 160 feet, and along the cliff on the west side of the Illinois River in the Tahlequah Quadrangle it is well over 100 feet.

General character.—Equal amounts of thin, alternating, regularly bedded, fine-grained, dense, and sparsely fossiliferous limestone and dark, blue-gray or black chert make up the Reeds Spring formation. The chert bands are so continuous that, as Moore has expressed it, a fresh outcrop gives the impression of "a horizontally banded wall." Limestone beds at the base of the formation are massive, but near the top they become thinner and the limestone and chert layers are about equal in amount and thickness. This lithologic character persists throughout the southern Ozarks. Siebenthal used the Grand Falls chert as a datum plane in making a subsurface contour map of the Joplin district.

Lead and zinc are mined from the Grand Falls formation in the Tri-State district.

Where the St. Joe forms an escarpment the Reeds Spring commonly retreats at a more gentle angle; good exposures of the latter formation are relatively few because outcrops are in most places covered by a heavy mantle of chert talus.

Stratigraphic relations.—At two places in the vicinity of Noel, Missouri, there is complete gradation from the St. Joe into the Reeds Spring and at the type section of the Reeds Spring the two formations seem to be conformable. At several places in Oklahoma (notably the outcrops along Spavinaw Creek and along Spring Creek) the formations are conformable with each other. In northern Arkansas the Reeds Spring in many places appears to be followed conformably by the lower Burlington limestone. The unconformity which Purdue and Miser (1916, p. 11) noted on War Eagle Creek is between strata of Fern Glen age [the Reeds Spring] and Burlington and it shows that, locally at least, there is an unconformity of slight time value separating the Reeds Spring and the overlying Burlington. In southwestern Missouri, Keokuk limestone rests unconformably on the Grand Falls and the Reeds Spring. In Oklahoma at several localities there is lower Burlington limestone which is stratigraphically above the Reeds Spring.

Faunal character.—Most of the fossils found in the Reeds Spring

are also found in the St. Joe, but certain significant differences may be noted. The presence of *Schizoblastus sayi* Shumard s.l., *Proetus ellipticus* M. and W., and a productid similar to *Dictyoclostus fernglenensis* (Weller), but larger, in the Reeds Spring, serve to differentiate the Reeds Spring and St. Joe faunas. The faunal list below includes all of the species which are known from the Reeds Spring formation. Most of the fossils listed were obtained by Moore from two localities, one east of Crane and the other at Grand Falls, Missouri, and they were listed in his paper in 1928 (pp. 191–192); as he recorded no fossils from the type section which he designated for the formation, the writer is here listing (Table II) 29 species which he collected at Reeds Spring, together with those which occur in small collections which were obtained from the Reeds Spring at Noel, Missouri, and from two places in Oklahoma.

TABLE II
Fossils from Reeds Spring Formation

	a	b	c	d	e	f
Cyathaxonia minor Weller	—	×	—	—	—	—
Cyathaxonia arcuata Weller	×	×	—	—	—	—
Homalophyllum calceolum White?	—	×	—	—	—	—
Zaphrentis sp.	—	—	×	—	—	—
Zaphrentis sp.	×	—	—	—	—	×
Favosites valmeyerensis Weller	×	—	—	—	—	×
Schizoblastus sayi Shumard s.l.	×	—	—	—	?	—
Fenestella rudis Ulrich?	—	×	—	—	—	—
Fenestella sp. cf. *F. triserialis* Ulrich	—	×	—	—	—	—
Fenestella sp.	—	×	—	—	—	—
Fenestella sp.	—	×	—	—	—	—
Fenestella sp.	—	×	—	—	—	—
Fenestella sp.	×	—	—	—	—	—
Evactinopora sexradiata M. and W.	×	×	—	×	—	—
Cystodictya sp.?	—	—	—	—	×	—
Leptaena analoga (Phillips)	×	—	—	—	—	—
Schuchertella fernglenensis Weller?	—	—	×	—	—	—
Schellwienella sp. cf. *S. burlingtonensis* Weller	—	—	×	—	—	—
Schellwienella sp. cf. *S.* sp. (Pierson l.?)	—	×	—	—	—	—
Streptorhynchus n. sp.	—	×	—	—	—	—
Chonetes illinoisensis Worthen	—	—	×	—	—	—
Chonetes burlingtonensis Weller	—	—	×	—	—	—
Chonetes ornatus arkansanus Girty	—	—	×	—	—	—
Chonetes logani N. and P.	—	—	—	×	—	—
Chonetes n. sp.	—	—	×	—	—	—
Chonetes sp.	—	—	×	—	—	—
Linoproductus ovatus (Hall)	×	—	×	?	—	—
Dictyoclostus fernglenensis (Weller)	×	—	?	?	—	—
Dictyoclostus n.sp. aff. *D. fernglenensis* (Weller)	—	—	—	×	—	×
Dictyoclostus? sampsoni (Weller)	×	—	?	—	—	—
Dictyoclostus? newtonensis (Moore)	—	—	×	—	—	—
Dictyoclostus? sp.	—	—	×	—	—	—
Pustula? newarkensis Moore	—	—	×	×	—	—
Pustula? sp.	—	—	×	—	—	—
Pustula? n. sp.	—	—	×	—	—	—

TABLE II (*Continued*)

FOSSILS FROM REEDS SPRING FORMATION

	a	b	c	d	e	f
Echinoconchus n. sp.	×	–	–	–	–	–
Productella concentrica (Hall)	–	–	×	×	–	–
Rhipidomella jerseyensis Weller	×	–	×	–	–	–
Rhipidomella tenuicostata Weller	–	×	–	–	–	–
Rhipidomella sp.	×	–	–	–	–	–
Schizophoria poststriatula Weller	–	–	?	–	×	–
Camarophoria bisinuata (Rowley)	–	–	?	–	–	–
Tetracamera subtrigona (M. and W.)	–	–	?	–	–	–
Rhynchopora? persinuata (Winchell)	×	–	×	–	–	×
Dielasma? sp.	–	–	×	–	–	–
Punctospirifer subtexta (White)	×	×	–	×	–	–
Punctospirifer subelliptica (McChesney)?	×	–	–	–	–	–
Spirifera shepardi Weller	–	–	×	–	–	–
Spirifera rowleyi Weller	×	×	×	–	–	–
Spirifera louisianensis Rowley	×	×	×	–	–	–
Spirifera osagensis Swallow	–	–	×	–	–	–
Spirifera buehleri Moore	–	–	×	–	–	–
Spirifera carinatus Rowley	×	–	–	–	–	×
Brachythyris chouteauensis Weller	×	?	×	–	–	–
Brachythyris suborbicularis (Hall)	–	–	?	–	–	–
Pseudosyrinx sp. cf. *P. keokuk* Weller	–	–	×	–	–	–
Ptychospira sexplicata (W. and W.)	×	×	–	–	–	–
Hustedia circularis (Miller)	?	–	–	–	–	–
Reticularia cooperensis (Swallow)	×	–	×	×	–	–
Athyris lemellosa (Léveillé)	–	×	×	–	–	–
Cliothyridina prouti (Swallow)	×	×	–	–	–	–
Cliothyridina tenuilineata (Rowley)	×	×	–	–	–	–
Cliothyridina glenparkensis Weller	×	–	×	–	–	–
Cliothyridina obmaxima (McChesney)	–	×	–	?	–	–
Nucleospira barrisi White?	×	–	–	–	–	–
Edmondia? sp.	–	–	×	–	–	–
Aviculopecten sp.	–	–	×	–	–	–
Platyceras paralius (W. and W.)	×	×	–	–	–	–
Strophostylus bivolvis (W. and W.)	×	–	–	–	–	–
Phillipsia? sp.	–	–	×	–	–	–
Griffithides? sp.	–	×	–	–	–	–
Griffithides? sp.	–	–	–	×	–	–
Proetus ellipticus M. and W.	×	–	–	–	?	–

a. Type section of the Reeds Spring; collected by writer.
b. East of Crane, Missouri; listed by Moore.
c. Shoal Creek near Grand Falls, Missouri; listed by Moore.
d. Noel, Missouri; collected by writer.
e. Spavinaw, Oklahoma, at dam; collected by writer.
f. South of the bridge over Spring Creek, 5.5 miles south of Locust Grove, Oklahoma; collected by writer.

Correlation.—Moore (p. 191) in 1928 believed the Reeds Spring to be the "time equivalent of at least part of the lower division of the Burlington. It may be in part, or even entirely, slightly older than Burlington." However, he recently announced (1933, pp. 203–204) that a study of the type section of the Fern Glen formation near St. Louis "shows the presence of stratigraphic units corresponding to the

Sedalia and Reeds Spring limestones," and that "a disconformity above the Reeds Spring limestone and a marked difference in faunal characters serve to separate beds of Fern Glen age from the succeeding Burlington limestone." From the vicinity of Salina, Oklahoma, the writer has obtained additional evidence which supports Moore's most recent conclusions; here in a coarsely crystalline crinoidal limestone, which is stratigraphically above the Reeds Spring, a fauna occurs which is almost identical with the fauna that Girty (1915b) described from the lower portions of the limestone [lower Burlington] which lies above beds of Fern Glen age at St. Joe, Arkansas. Also, the fauna from Salina can be duplicated for the most part by species that occur in the white chert of the lower Burlington at Louisiana, Missouri. Thus, it seems that the Reeds Spring is pre-Burlington in age.

BURLINGTON FORMATION

In extreme southwestern Missouri beds of Burlington age seem to be generally absent. In the vicinity of Springfield the presence of the *Dizygocrinus rotundus* fauna[5] shows clearly that the containing beds are of upper Burlington age. As the upper Burlington is traced southwestward from Springfield it apparently thins and according to Moore (1928, p. 143), in the vicinity of Joplin it is missing entirely and Keokuk limestone rests on the Reeds Spring formation. After having collected and identified fossils from many outcrops in southwestern Missouri the writer also is inclined to this view.

Burlington limestone and chert is widespread in northern Arkansas. Here the chert content varies greatly from place to place, but in north-central Arkansas where fresh exposures are seen the formation is a gray, coarsely crystalline, crinoidal limestone that closely resembles the Burlington of the Middle Mississippi Valley.

From St. Joe, Arkansas, Girty (1915b) has described a Burlington fauna. The writer has obtained topotype material from this locality and a study of the fauna shows that its relations are with the lower Burlington. Limestone about 30 feet below the top of the Osage group in this same section contains abundant representatives of *Spirifer grimesi*, and it seems best to regard it as upper Burlington in age. In a road cut 7.1 miles east of St. Joe there is exposed a gray crinoidal limestone which appears to represent approximately the same horizon.

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[5] In an unpublished thesis at the State University of Iowa, L. R. Laudon has established four zonules within the upper Burlington limestone of Iowa; the second of these zonules is characterized by the *Dizygocrinus rotundus* fauna.

In Arkansas the easternmost outcrops of the Osage are in the vicinity of Batesville. Here Girty (1915a) recognized three "members" of the "Boone formation," the lower one cherty and unfossiliferous, the middle one a limestone, and the upper member a fossiliferous chert. The lower cherty member, which is about 150 feet thick, rests on St. Clair limestone at a place which is a short distance southeast of Big Spring Mill. No fossils have been obtained from this member, but the abundance of black chert which closely resembles the variety so widespread in the Reeds Spring formation leads the writer to believe that this member is an eastward extension of the Reeds Spring. Although the middle limestone member is sparingly fossiliferous, the fossils are poorly preserved. Girty (1928) identified 45 species of fossils in his collections from this member, and decided (p. 76) that they represented an undifferentiated Burlington and Keokuk fauna. In company with Laudon the writer has studied the exposures of the "middle Boone" where they crop out along Spring Creek. The fossils which they collected are, like those studied by Girty, extremely poorly preserved, but definite representatives of the following species were taken from limestone in an abandoned quarry near Denieville.

Chonetes illinoisensis Worthen	*Spirifer incertus* Hall
Dictyoclostus viminalis (White)?	*Brachythyris suborbicularis* (Hall)
Dictyoclostus burlingtonensis (Hall)	*Syringothyris platypleurus* (Weller)
Spirifer grimesi Hall	*Reticularia pseudolineata* (Hall)
Spirifer carinatus Rowley	*Platyceras latum* Keyes

This fauna, though not large, bespeaks a Burlington age for at least that portion of the "middle Boone" from which they came. It must be borne in mind, however, that Girty's collections were much more extensive than ours and it is entirely possible that Keokuk beds do occur above the Burlington portion of this "member."

Purdue and Miser (1916, p. 11) stated that the "Boone" of the Eureka Springs-Harrison quadrangles is about equally divided between the Burlington, the Keokuk, and the Warsaw. Some of the "common and more significant" fossils found in the lower half of the Osage were listed and they were said to indicate a Burlington age for this portion of the group. These authors did not cite localities from which the fossils were collected, but their list is clearly that of a Burlington assemblage. A recent road-building program in these two quadrangles has resulted in many new road cuts in which it is now possible to study fresh exposures of the Osage. A good section of the lower Osage is exposed from Willcockson northward for more than a mile and the following fossils were collected there by the writer.

Eretmocrinus neglectus (M. and W.)?

Uperocrinus pyriformis (Shumard)

Dorycrinus missouriensis (Shumard)?

Actinocrinus griffithi W. and Sp.?

Steganocrinus pentagonus (Hall)

Cactocrinus glans (Hall)

Platycrinus glyptus Hall?

Eucladocrinus pleurovimeneus (White)?

Dichocrinus striatus Owen and Shumard

Barycrinus sp.

Chonetes illinoisensis Worthen

Dictyoclostus viminalis (White)

Schizophoria swallovi (Hall)

Delthyris similis Weller

Spirifer grimesi Hall

Brachythyris suborbicularis (Hall)

Spiriferella plena (Hall)

Platyceras paralius (W. and W.)

The occurrence of well preserved crinoid calyces is rather unusual in this southern extension of the Osage. The well known species listed above all occur in the Burlington limestone in the vicinity of the type section in Iowa. Most of the brachiopods listed came from the lower few feet of the section, but the crinoids were found near the top and were not confined to any particular zone. The lower part of the section is probably lower Burlington in age, but the beds containing the crinoids are upper Burlington.

There has been little unanimity of opinion as to the age of the "Boone chert" of Oklahoma. Taff (1905, p. 3) referred the upper fossiliferous cherts of the Tahlequah Quadrangle to the Keokuk and published a list of fossils from these cherts. In 1915 Snider (p. 25) said that the lower cherts carry a Burlington fauna; the writer believes that the lowermost chert is of Reeds Spring age, and evidence will be presented later to show that the upper part of the chert is Burlington. Snider stated that the fossils which occur in the upper cherts which Taff had called Keokuk were lower Warsaw, and Buchanan (1927, p. 1314) thought that the lower portions of the chert [the Reeds Spring] were late Burlington. Cram (1930, p. 559) believes that the upper Burlington beds are missing in Oklahoma.

About a mile and a half northwest of Salina, Oklahoma, on the south side of the Pryor road, an Osage inlier rises through the younger Mayes formation. This hill has been cited by several previous writers as one of a number of "buried hills" which now rise through the formations of Meramec and Chester age. The strata in this hill have been tilted to the northeast at a low angle and here typical Osage chert is underlain by a coarsely crystalline crinoidal limestone. The limestone is very fossiliferous and has yielded a large fauna. Most of the species of brachiopods in the fauna are also known to occur in the white chert of the lower Burlington limestone at Louisiana, Missouri, and these brachiopods show definitely that the beds at Salina are also of lower Burlington age. Comparison of the Salina fauna with the fauna which occurs above the Reeds Spring at the type section of the St. Joe in Arkansas reveals that there are many species in common and that the limestones in these two widely separated localities

are closely similar in age. In Table III are listed all of the species that Girty collected from the limestone at St. Joe together with additional specimens obtained at the same place by the writer, and all of the species that the writer was able to procure from the Salina section.

TABLE III

FAUNAL LIST OF LOWER BURLINGTON

	a	b	c
Amplexus fragilis White and St. John.............	×	×	×
Fenestella rudis Ulrich........................	—	×	—
Fenestella sp. aff. *F. burlingtonensis* Ulrich.........	×	—	—
Fenestella sp.......................	×	—	—
Fenestella sp. a (of Girty)......................	—	×	—
Fenestella sp. a, b, c, and d (of Girty).............	—	×	×
Hemitrypa, n. sp........................	—	×	—
Polypora, n. sp........................	—	×	—
Rhombopora sp........................	×	—	—
Cystodictya lineata Ulrich....................	×	×	—
Schuchertella fernglenensis Weller?...............	×	—	—
Chonetes illinoisensis Worthen...................	×	—	—
Chonetes ornatus arkansanus Girty................	—	×	×
Dictyoclostus burlingtonensis (Hall)...............	—	×	×
Dictyoclostus aff. *D. fernglenensis* (Weller).........	×	—	—
Linoproductus ovatus (Hall).....................	×	—	—
Productella, n. sp. [*P. concentrica* Girty]..........	×	×	×
Productella concentrica (Hall) [*P. semicostata* Girty]..	×	×	×
Productella millespinosa Girty....................	×	×	×
Productella patula Girty.......................	×	×	—
Rhipidomella diminutiva Rowley.................	×	—	×
Schizophoria poststriatula Weller................	×	—	—
Schizophoria swallovi (Hall)....................	×	×	—
Camarotoechia tuta (Miller).....................	×	—	—
Cranaena globosa Weller.......................	×	—	—
Cranaena, n. sp............................	×	—	—
Rhynchopora persinuata (Winchell) [*R. pinguis* Girty]	×	×	×
Rhynchopora sp............................	—	×	—
Cyrtina neogenes Hall and Clarke................	×	—	—
Cyrtina burlingtonensis Rowley..................	×	—	—
Delthyris novamexicana (Miller).................	×	—	—
Punctospirifer aff. *P. subtexta* (White).............	—	×	—
Spirifer louisianensis Rowley...................	×	—	—
Spirifer incertus Hall?........................	×	—	—
Spirifer grimesi Hall?........................	—	×	—
Spirifer carinatus Rowley?.....................	—	×	—
Spiriferella? schucherti (Rowley)................	×	—	—
Brachythyris chouteauensis Weller...............	×	—	×
Brachythyris suborbicularis (Hall)...............	×	×	×
Pseudosyrinx missouriensis Weller...............	×	—	—
Ambocoelia levicula Rowley....................	×	—	—
Ambocoelia parva Weller......................	×	—	—
Reticularia pseudolineata (Hall).................	?	×	—
Reticularia cooperensis (Swallow)?...............	—	—	×
Ptychospira sexplicata (W. and W.)..............	×	—	—
Athyris lamellosa (Lèveillè)...................	—	×	—
Cliothyridina glenparkensis Weller...............	×	—	—
Cliothyridina hirsuta Hall?....................	—	×	—
Cypricardina rugosa Girty.....................	×	×	—

TABLE III (*Continued*)
FAUNAL LIST OF LOWER BURLINGTON

	a	*b*	*c*
Cardiomorpha orbicularis Girty..................	—	×	—
Conocardium sp.................................	×	—	—
Platyceras equilatera Hall.......................	—	×	—
Platyceras paralius (W. and W.).................	×	—	—
Coelonautilus sp................................	—	×	—
Brachymetopus? elegans Girty...................	×	×	—

a. From outcrop on hill on south side of Salina-Pryor road, 1.5 miles northwest of Salina. Collected by writer.

b. Listed by Girty as occurring near St. Joe, Arkansas.

c. Same locality as last but collected by writer.

A little more than a mile west of Salina and about a mile southeast of the lower Burlington outcrop already referred to, dark Chester limestone rests unconformably on light Osage chert. Herewith is a list of fossils that occur in the chert.

Productella concentrica (Hall)	*Spirifer carinatus* Rowley?
Linoproductus ovatus (Hall)	*Brachythyris chouteauensis* Weller
Dictyoclostus, n. sp.	*Reticularia pseudolineata* (Hall)
Echinoconchus alternatus (N. and P.)	*Cliothyridina glenparkensis* Weller
Cranaena globosa Weller	*Cardiomorpha* sp.
Cyrtina neogenes Hall and Clarke	

This chert, probably lower Burlington in age, is believed to represent a slightly higher horizon than the lower Burlington limestone northwest of Salina.

A thick section of Osage chert is exposed in the north bluff of Spavinaw Creek about 2.5 miles above its junction with Grand River. The Reeds Spring formation, which crops out in the lower part of the cliff, has already been mentioned under the discussion of that formation, but above it there is about 45 feet of lighter-colored chert which is referable to the Burlington. Fossils are rare in this chert but a few have been obtained from five different zones. The first zone is 12 feet above the top of the Reeds Spring formation; the second is 15 feet higher than zone number one; zone three is 3.5 feet above zone two; zone four is 4.5 feet above zone three; 10 feet above zone four is zone five. Table IV shows the distribution of the fossils in the various zones.

The lower zones seem to represent approximately the same horizon as that represented by the chert one mile west of Salina, but zone five may possibly be slightly younger.

From residual boulders on top of the hill in the Spavinaw Creek section representatives of *Spirifer carinatus* Rowley, *Spirifer*, n. sp. aff. *S. carinatus* Rowley, and *Dielasma oscoelense* Weller have been

TABLE IV

BURLINGTON CHERT EXPOSED ON SPAVINAW CREEK 2.5 MILES ABOVE
JUNCTION WITH GRAND RIVER

	1	2	3	4	5
Aulopora gracilis Keyes...............	X	—	—	—	—
Fenestella sp......................	X	—	—	—	—
Archeocidaris sp.....................	—	X	—	—	—
Orthotetes? sp......................	X	—	—	—	—
Chonetes multicostata Winchell.........	X	—	X	—	X
Chonetes illinoisensis Worthen..........	—	—	X	—	X
Dictyoclostus sp....................	—	—	X	—	—
Dictyoclostus, n. sp...................	X	X	X	X	X
Pustula sp........................	X	—	—	—	—
Rhipidomella diminutiva Rowley.......	—	—	X	—	X
Dielasma oscoelense Weller...........	—	—	X	—	—
Delthyris similis Weller.............	—	—	X	—	X
Cyrtina neogenes Hall and Clarke.......	—	—	X	—	—
Spirifer louisianensis Rowley.........	X	X	—	—	—
Spirifer, n. sp. aff. *S. carinatus* Rowley..	X	—	—	X	—
Spirifer carinatus Rowley.............	—	X	—	—	—
Spirifer sp. indt....................	—	—	—	—	X
Pseudosyrinx? sp....................	—	X	—	—	—
Reticularia pseudolineata (Hall)........	—	—	—	X	—
Pleurotomaria? sp...................	—	—	X	—	—
Griffithides? sp.....................	—	—	X	—	—

collected. Although these same species range downward into beds which are being referred to the lower Burlington, the absence of such types as *Spirifer louisianensis* Rowley, *Chonetes multicostata* Winchell, and *Rhipidomella diminutiva* Rowley seem to indicate a younger age, and it seems likely that the upper Burlington beds were once represented in this section. In several other places in Oklahoma there are chert beds which are of upper Burlington age, and *Spirifer carinatus* Rowley is one of the most abundant fossils at these localities. The holotype of this species came from the top part of the lower Burlington limestone at Louisiana, Missouri, but in Oklahoma its association with such forms as *Dielasma oscoelense* Weller, *Pentremites elongatus* (Shumard), and *Tetracamera subtrigona* (M. and W.) shows that it ranges into the upper Burlington.

At several places west of Spavinaw on the Spavinaw-Tulsa road there are residual boulders which contain upper Burlington fossils. At one such locality, which is about 3 miles west of Spavinaw, the writer has collected the following fossils from residual boulders.

Aulopora gracilis Keyes   *Spirifer*, n. sp. aff. *S. carinatus* Rowley
Orthotetes keokuk Hall?   *Spirifer carinatus* Rowley
Dictyoclostus mesialis (Hall)   *Spirifer* sp. aff. *S. vernonensis* Swallow
Spirifer milleranus Butts

In addition to the foregoing species Laudon has collected *Pentremites elongatus* (Shumard) and *Dielasma oscoelense* Weller from

the same locality. *Spirifer milleranus* Butts is abundant at this horizon in several places in Oklahoma, and apparently it is this species that most writers have referred to *S. logani* Hall and which they have thought to be indicative of Keokuk age. The writer has collected fossils from most of the localities in Oklahoma from which previous workers have listed Keokuk fossils, but in all of his collections there is not even one *Spirifer* that can be referred to *S. logani* Hall; *S. milleranus* Butts superficially resembles *S. logani*, but a close examination reveals that *S. milleranus* is more closely plicate, has a less pronounced fold and sinus, and is less gibbous than *S. logani*. The type of *S. milleranus* was collected from the Logan? sandstone of the New Providence group of western Kentucky.

Overlying lower Burlington limestone in the section one and one-half miles northwest of Salina there is a white fossiliferous chert which has yielded the following fossils.

Fenestella sp.	*Brachythyris suborbicularis* (Hall)?
Tetracamera subtrigona (M. and W.)	*Pseudosyrinx missouriensis* Weller
Spirifer carinatus Rowley	*Athyris lamellosa* (Lèveillè)

The presence of *Tetracamera subtrigona* (M. and W.) might indicate that the fauna is a Keokuk assemblage, but Laudon has found that this fossil is abundant in the upper Burlington limestone of southeastern Iowa (adjacent to the type section) and there are in the repository at the State University of Iowa abundant representatives of this species which were obtained from the upper Burlington of that state.

In Sec. 25, T. 20 N., R. 19 E. Chester limestone rests with distinct unconformity on Osage limestone and chert. Fossils found in the Osage at this place are the following.

Zaphrentis centralis (M. E. and H.)	*Spirifer carinatus* Rowley
Orthotetes keokuk Hall	*Spirifer*, n. sp. aff. *S. carinatus* Rowley
Chonetes logani N. and P.	*Syringothyris typus* Winchell
Dictyoclostus burlingtonensis (Hall)	*Reticularia pseudolineata* (Hall)
Dictyoclostus, n. sp.	*Cardiomorpha* sp.
Rhipidomella diminutiva Rowley?	*Bellerophon* sp.
Tetracamera subtrigona (M. and W.)	*Platyceras paralius* (W. and W.)
Dielasma sp.?	*Griffithides? portlocki* M. and W.

As the containing beds are believed to be upper Burlington in age, they represent approximately the same horizon as the three previously discussed sections which have been referred to the upper Burlington.

An excellent exposure of Osage limestone and chert crops out in the bluffs of Honey Creek in Sec. 19, T. 24 N., R. 25 E. Alternating dark-colored unfossiliferous limestone and chert cropping out in the

lower portions of the cliff probably represent the top of the Reeds Spring formation. Thirty feet above the base of the section the first fossils were found; at three other zones which are 10, 13, and 23 feet respectively above zone one, additional fossils were obtained. The faunal chart (Table V) shows the distribution and range of the species in this section.

TABLE V
BURLINGTON FORMATION ON HONEY CREEK, SEC. 19, T. 24 N., R. 25 E.

	1	*2*	*3*	*4*
Triplophyllum dalei (M. E. & H.)?	–	–	–	×
Zaphrentis sp.	–	–	–	×
Schellwienella alternata Weller	×	–	–	–
Schellwienella sp.	×	–	–	–
Ortholetes keokuk Hall?	×	–	–	–
Chonetes illinoisensis Worthen	×	×	×	×
Chonetes multicostata Winchell	–	–	–	×
Dictyoclostus, n. sp.	–	–	–	×
Dictyoclostus sp. aff. *D. burlingtonensis* (Hall)	–	–	–	×
Linoproductus ovatus (Hall)	×	–	–	–
Echinoconchus alternatus (N. and P.)	–	–	–	×
Schizophoria swallovi (Hall)	–	×	×	–
Camarophoria bisinuata (Rowley)	–	–	–	×
Rhynchopora? cooperensis (Shumard)	×	–	–	×
Tetracamera subcuneata (Hall)	×	–	–	–
Cranaena globosa Weller	–	×	×	×
Cyrtina neogenes Hall and Clarke	–	–	–	×
Delthyris similis Weller	×	×	–	–
Spirifer carinatus Rowley	×	–	–	–
Spirifer grimesi Hall	–	–	×	–
Spirifer, n. sp.	–	×	–	–
Spirifer sp.	–	–	–	×
Brachythyris suborbicularis (Hall)	–	–	–	×
Pseudosyrinx missouriensis Weller	×	–	–	–
Reticularia pseudolineata (Hall)	×	×	–	×
Acambona prima White	–	–	–	×
Cliothyridina glenparkensis Weller	–	–	–	×
Composita sp.	×	–	–	–
Cardiomorpha sp.	–	×	–	–
Cypricardina rugosa Girty	×	–	–	–
Myalina sp.	–	–	–	×
Pleurotomaria sp.	–	×	–	×
Griffithides? sp.	–	×	–	×

There can be no doubt as to the lower Burlington age of this fauna. It represents the same horizon as the limestone section northwest of Salina which has been referred to several times; also it would correlate with the lower Burlington limestone that occurs above the Reeds Spring formation in the type section of the St. Joe formation in Arkansas.

Stratigraphic relations.—In southwestern Missouri beds of Burlington age seem to be missing.

In northern Arkansas lower Burlington rests with apparent con-

formity upon the Reeds Spring formation and it is followed by upper Burlington limestone and chert which in turn is overlain in some places by Keokuk beds and in other places by strata of post-Warsaw age.

The Reeds Spring underlies the Burlington in all of its exposures which have been seen in northeastern Oklahoma. It is the opinion of the writer that Keokuk beds are not present in Oklahoma except possibly for a small area in the extreme northeast part of the state; here, according to Siebenthal (1907b, p. 190), there is an oölite that correlates with the Short Creek oölite of the Joplin, Missouri, district. At the westernmost outcrops of the Burlington in Oklahoma, Chester limestone overlies it with pronounced unconformity. The unconformable contact of the Burlington with the younger formations may be seen in the section 1½ miles northwest of Salina, at a place about a mile west of Salina, and in several places in Sec. 25, T. 20 N., R. 19 E. Because of pre-Mayes erosion the Burlington becomes progressively thinner as it is traced southward, and in the vicinity of Marble the formation is only about 30 feet thick and is overlain by Chester limestone and shale.

KEOKUK FORMATION

Moore (1928, p. 143) has stated that in southwestern Missouri the Reeds Spring formation is overlain unconformably by the Keokuk limestone. The writer has had the opportunity of examining many of the Keokuk sections described by Moore in the vicinity of Joplin and Neosho and has collected fossils zone by zone from a number of outcrops, but he has nothing new to add to Moore's discussion of that formation.

According to Girty (1930), Keokuk fossils occur in the "middle Boone" at Batesville, Arkansas. Purdue and Miser (1916) believe that Keokuk limestone follows the Burlington in Boone County, Arkansas. However, it may be added that their "significant list of fossils" from the "upper Boone" includes names of many fossils that the writer regards as being more diagnostic of Burlington than Keokuk. It appears that in most places in northern Arkansas where Osage formations form the surface rock, the outcropping beds are not younger than upper Burlington. At the type section of the St. Joe the Keokuk is not represented and black shale lies above the Burlington. However, it seems likely that in such thick sections of the Osage as the one which is exposed south of Jasper, Keokuk beds occur above the Burlington, but the writer has made only a hasty examination of this section.

WARSAW FORMATION

According to Moore (1928, p. 232), the Warsaw in southwestern Missouri consists of about 100 feet of bluish gray-to-buff crystalline limestone. An oölitic bed (the Short Creek oölite) 2–8 feet thick comprises the basal member of the formation and is said to rest disconformably upon Keokuk limestone. The writer has studied several Warsaw sections which Moore described, and has collected and studied fossils from some of these (notably the outcrops in the vicinity of Carthage). There seems to be little doubt as to the Warsaw age of the *Productus* [*Dictyoclostus*] *magnus* fauna of this area.

Girty believes that the "upper chert member" of the "Boone" of the Batesville, Arkansas, district is Warsaw in age (1928, p. 76); nevertheless he has stated that it carries a fauna that is similar to that of the underlying "Spring Creek" limestone. The writer has also studied the "Boone" in the vicinity of Batesville and has reached the conclusion that the "upper cherty member" of Girty rests unconformably on the "middle Boone." In a quarry which is about 2 miles north of Batesville on the Blowing Cave road, the base of this chert may be seen and its contact with the underlying limestone is very irregular. The chert differs lithologically from the chert of the Osage group. In view of this apparent unconformity and because the "*Liorhynchus carboniferum*" fauna of this chert is markedly different from the fauna of the underlying "middle Boone," it is the opinion of the writer that the chert should not be classed with the underlying Osage beds. The fauna of the "Spring Creek" beds has been erroneously termed the "Moorefield fauna" by some writers because Girty[6] at one time classed the "Spring Creek" as the basal unit of the Moorefield shale. Girty subsequently recognized that the "Spring Creek" limestone should not be classed with the Moorefield and the present writer is equally sure that the limestone and the underlying chert which carries the same fauna should not be classed with the Osage beds (Boone formation of previous reports). The name "Spring Creek" is invalid and the limestone that has gone by that name together with the underlying chert of the same age should have another name applied to it. The "*Liorhynchus carboniferum*" fauna is represented in the Mayes formation of northeastern Oklahoma, in the lower Caney shale of the Arbuckle Mountain region, in the Llano-Burnet uplift in central Texas, in beds that Girty (1926) has referred to the "Boone," and possibly in western Texas. Some geologists think that this fauna is Meramec but there seems to be a growing tendency to re-

[6] George H. Girty, "The Fauna of the Moorefield Shale of Arkansas," *U. S. Geol. Survey Bull. 439* (1911).

gard it as Chester. The writer inclines to the latter interpretation. In any event there is a marked unconformity between beds containing the "Spring Creek" fauna and the underlying Osage group. Snider (1915, p. 26) has shown that in northeastern Oklahoma there is an erosional unconformity between the Osage and the Mayes (the lower part of Snider's Mayes contains a "Spring Creek" fauna), and the writer has mentioned elsewhere in this paper evidence which confirms Snider's statement.

Purdue and Miser (1916, p. 10) noted an oölitic limestone in the Eureka Springs and Harrison quadrangles in Arkansas and they correlated it with the Short Creek oölite, but, as has been pointed out by Croneis (1930, p. 47), the evidence for this correlation is not conclusive. Although strata of Warsaw age may be present in Boone County, Arkansas (which has approximately the same boundaries as the Eureka Springs-Harrison quadrangles), it seems that the Osage beds there are not younger than the Keokuk. In order that this statement may not be misinterpreted, it should be mentioned that the writer agrees with Moore that the Warsaw should be properly included in the Osage group and not in the Meramec.

According to Siebenthal (1907b, p. 190), there is an oölite in the Wyandotte Quadrangle, Oklahoma, which is the correlative of the Short Creek oölite of the Joplin, Missouri, district, but it seems to be confined to a small area, and in other places in northeastern Oklahoma the Warsaw, like the Keokuk, is absent.

Buchanan, in 1927, expressed the opinion that as the Osage cherts are traced westward and southward in Oklahoma they disappear because of an erosional unconformity. In 1930 Cram (p. 563) published cross-sections showing his and Buchanan's interpretations of the "Boone" as it is traced underground to the southwest. Cram (p. 564) believes that the Osage cherts and the Mayes formation both grade laterally into the lower Caney shale of the Arbuckles. As is shown below, the writer has obtained evidence which militates against Cram's interpretation, and he agrees with Snider and Buchanan that there is an erosional unconformity separating the Osage and Mayes; also he concurs with Buchanan in the belief that south and west of its outcrops the Osage is cut out (and not replaced by shale), although the Mayes from faunal evidence is known to be the direct lateral equivalent of the lower Caney. At a place a little more than a mile from Salina, beds of Chester age rest on lower Burlington chert. In the hill just west of the old abandoned quarry at Marble the Osage, due to an unconformity at the top, has thinned to such an extent that only about 35 feet of the lower Reeds Spring formation remains. South
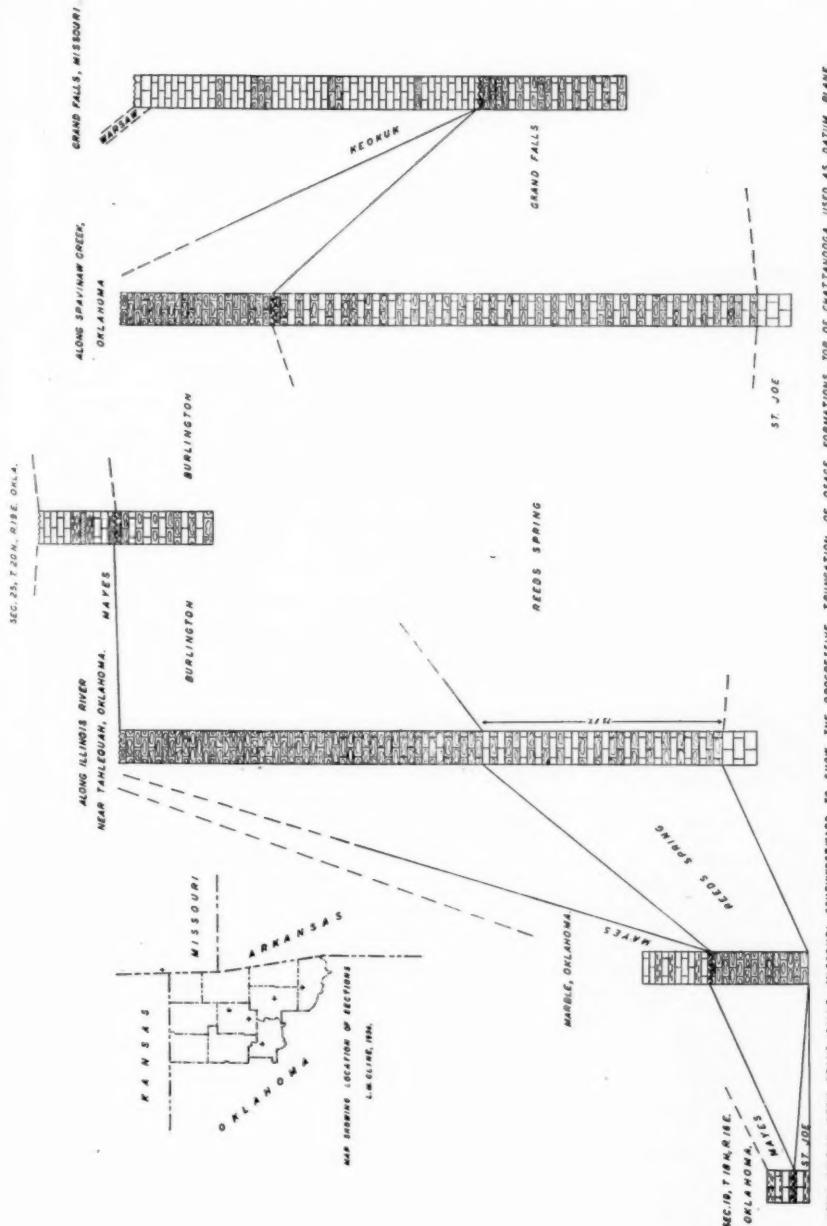
Fig. 2

CROSS-SECTION FROM GRAND FALLS MISSOURI SOUTHWESTWARD TO SHOW THE PROGRESSIVE TRUNCATION OF OSAGE FORMATIONS. TOP OF CHATTANOOGA USED AS DATUM PLANE.

of this outcrop the Osage dips under younger Mississippian and Pennsylvanian beds and it is probable that at no great distance south of its southernmost outcrop the group is cut out altogether.

Thus, columnar sections taken at intervals from Grand Falls, Missouri, and extending in a southwestward direction toward the Arbuckle Mountains in Oklahoma, show that in northeastern Oklahoma there was a post-Osage and pre-Mayes (Lower Caney = "Spring Creek" in age) period of erosion (Fig. 2). As this surface of unconformity truncates progressively older and older Osage strata as it is traced southwestward, it becomes of greater time value in this direction and it is evident from the exposed Osage-Mayes contacts that at this rate of progression the Osage must be entirely missing in the subsurface at a short distance southwest of the Mississippian-Pennsylvanian line of outcrops in the southern part of this area. F. A. Bush, of the Sinclair Oil Company, has reported[7] Simpson (Ordovician) detritus between Osage and Chester formations in a well in Sec. 15, T. 28 N., R. 3 W. in Oklahoma; this locality is west of the area of outcrop of Mississippian sediments. According to Johnston, also of Sinclair Oil Company, Mayes limestone rests unconformably on St. Joe in a well in Sec. 19, T. 18 N., R. 16 E. in Wagoner County. A portion of this last well section is reproduced in Figure 2. These two well logs show that the unconformity between the Osage and the Mayes, which is so evident in outcrops, continues in the subsurface.

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[7] Letter from L. A. Johnston, dated April 20, 1934.

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OIL POSSIBILITIES OF BELGIUM AND BELGIAN CONGO[1]

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ABSTRACT

The paper is a résumé of the petroleum situation of Belgium and the Belgian Congo in the light of recent investigations. Three prospective areas in Belgium are described; of these, the Campine is considered as the most favorable. In the Belgian Congo two areas are discussed at some length, the Central basin and the Rift valleys. These offer some possibilities for commercial production.

INTRODUCTION

At present there is no commercial oil or gas production in Belgium or in the Belgian Congo. The data on Belgium are based largely on the writer's acquaintance with the geology of the area and on a study of the literature on the subject. General suggestions have also been received from leading geologists in Belgium. For the Congo, the only available data dealing directly with the petroleum possibilities are published in the report by E. J. Wayland,[3] on petroleum in Uganda. Certain information concerning the Belgian Congo has also been obtained from the geological map of the Congo Colony by Fourmarier[4] and from the reports of the Société Géologique de Belgique.

The writer is indebted to F. M. Van Tuyl for helpful advice in connection with the preparation of this paper and for suggestions concerning the possibilities of petroleum and natural gas in the Belgian Congo.

BELGIUM

Three regions in Belgium may be considered as having possibilities of petroleum: (1) the Campine region, comprising the provinces of Limbourg, Anvers, and northern Brabant; (2) the Cretaceous basin of Mons; (3) the Foreland of the Midi fault comprising mainly the Dinant basin.

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[1] Presented by title before the Association at the Dallas meeting, March 24, 1934. Manuscript received, February 14, 1934.

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[3] E. J. Wayland, "Petroleum in Uganda," *Uganda Geol. Survey Mem. 1* (1926), p. 65.

[4] P. Fourmarier, "Carte Géologique du Congo Belge," *Revue Universelle des Mines*, Vol. III, No. 12 (June, 1930).

CAMPINE REGION

STRATIGRAPHY

The surface formations of the Campine region are late Tertiary and Pleistocene in age (Fig. 1). These beds were deposited in a geosyncline whose axis strikes east and west. The tilting of the region occurred in a northerly direction with minor changes of directions as the deposition of sediments occurred.
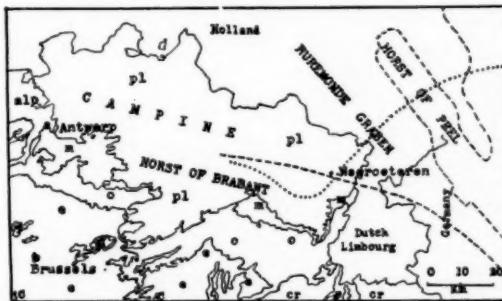
FIG. 1.—Areal geology of Campine region. *alp* = Pleistocene. *pl* = Pliocene. *m* = Miocene. *o* = Oligocene. *e* = Eocene. *cr* = Cretaceous. *p* = Carboniferous. *C* = Cambrian. . . . = possible limit of Zechstein formation.

TABLE I

Era	System	Series	Formation	Characteristics	Approximate Thickness (Feet)
	Pleisto-cene		Campinian	Sandy clays	75
		Pliocene	Amstelian	Unconsolidated sands Lignites in places	900
			Scaldisian	Unconsolidated sands	
			Distian	Unconsolidated sands	
		Miocene	Anversian	Unconsolidated sands, gravel	30
			Bolderian	Unconsolidated sands, gravel	
			Chattian	Sand and gravel (glauconitic) Conglomerate Clay in south	250
Ceno-zoic	Tertiary	Oligocene	Rupelian	Clay Unconsolidated sand	

TABLE I (Continued)

Era	System	Series	Formation	Characteristics	Approximate Thickness (Feet)
			Tongrian	Sand and marl of continental facies Sand and marl of marine facies	730
			Bartonian	Sand and clay	
			Ledian	Sand and gravel	?
			Bruxellian	Sand, unconsolidated	
		Eocene	Ypresian	Sand and clay	
			Landenian	Continental: sand and lignite Marine: sand and sandstone; clay and gravel (foraminifers)	160
			Montian	Limestone, in places oölitic	25
	Cretaceous		Tuffeau of Maestricht	Tuff	160
			Senonian	Gray clay	17
	Jurassic		Hettangian	Bituminous shales Limestones Numerous fossils (Schloteimia angulata)	200
Mesozoic			Rethian	Limestone	50
			Keuper	Red shales and salt Same facies as "Gyps Keuper" of Germany	270
	Triassic		Conchylian limestone	The three corresponding facies of Germany are represented: 1. Hauptmuschelkalk (red rocks and anhydrite) 2. Anhydrite Gruppe 3. Wellenkalk (showing ripple marks)	270
Paleozoic	Permian		Zechstein (?)	Dolomite Dolomitic limestone Conglomerate	?
	Pennsylvanian		Coal measures		?
Cambrian				Quartzite	?

The region as a whole may now be considered to be of great stability as shown by gravimetric measurements.[5] The region west and north of Bruxelles shows an excess of mass and a tendency to sink, whereas eastern Campine is on the limit of the region of mass deficiency. This accounts for the gentle dips of the surface formations in a northerly direction at the average rate of about 15 feet to the mile.

<div align="center">STRUCTURE</div>

The Cambrian basement on which the later Paleozoic, Mesozoic, and Cenozoic sediments were deposited dips regularly in a northerly direction at the rate of about 90 feet to the mile. This platform is limited on the north by an abrupt displacement, the Demer fault, which marks the southern boundary of the Ruremonde graben. In the latter, several parallel faults at Rottem, Neeroeteren and Eelen (Fig. 2) gradually increases the depth to the Paleozoic in such a way that in the northern part of the Campine region the coal measures occur at an estimated depth of more than 6,000 feet (Fig. 3).

The vertical displacements in the Paleozoic strata and younger sediments are superimposed on folds and faults produced by the Hercynian movements. The latter structures strike in a direction at right angles to the general direction of the Ruremonde graben. In the latter it has been found by drilling at Ven, that the Upper Oligocene was encountered at a depth (970 feet) much less than at Eelen and Molenbeersel (2,400–2,900 feet); consequently, there probably exists under the Ven region a horst similar to the one of Peel. However, there is no further proof of this than the data supplied by the shallow drilling at Ven. Hypothetical faults bordering this horst are indicated in Figure 3.

<div align="center">RELATION TO GEOLOGY OF NEIGHBORING COUNTRIES</div>

In 1905 André Dumont predicted the existence of coal measures of Pennsylvanian age underlying the Campine region on the basis of geologic analogy between the coal fields of the Ruhr district (Germany) and of the Carboniferous of the Midlands region of England. In each region the coal basin shows a general east-west trend. The views of Dumont were confirmed by core drilling with the result that extensive coal deposits have been developed in that region.

Comparative studies made thereafter in Belgium as well as in England have proved that the Cambrian of Brabant may be considered as the extension of the Basement rocks of the same age in

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[5] Jean Jung, "La géologie profonde de la France d'après le nouveau réseau magnétique et les mesures de la pesanteur," *Ann. de l'Inst. de Phys. du Globe*, Vol. 11 (1933).
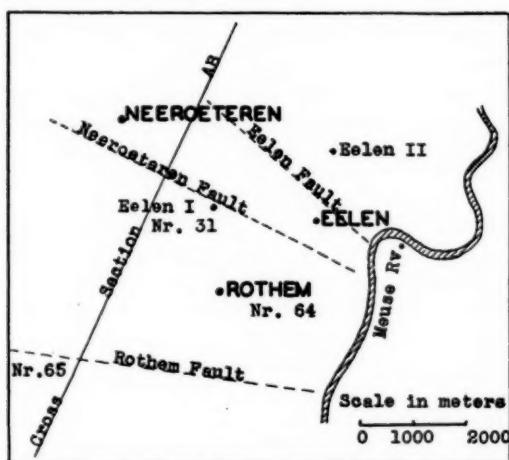
FIG. 2.—Fault system of Campine region. After Stainier.
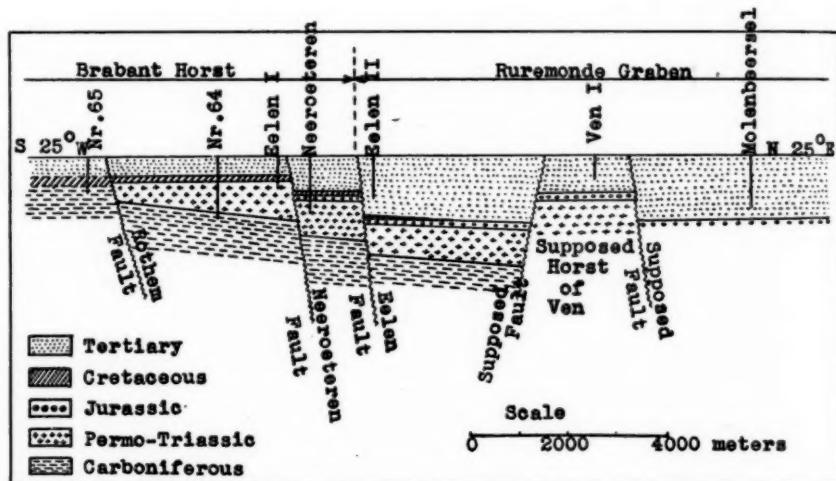
FIG. 3.—Cross section along AB (Fig. 2). After Stainier.

Wales (England). It is also inferred that the Campine and the Midlands regions belong to the same geologic unit, that is, to the geosyncline on the north of the Welsh Brabant anticline in which the existence of petroliferous horizons was established during the World War. However, no commercial oil pool has been found. On the other hand, comparison of the relatively undisturbed sediments of the Campine and of the Midlands shows strong reasons for believing that the Campine may be considered as a petroliferous province.

Petroleum may not only have been generated in the Carboniferous, but also in the Upper Mesozoic, as may be inferred from the geology of Holland and northwestern Germany. On the assumption of close relations between the geology of northern Belgium and of the North German Plain, considerable drilling was carried on in the years 1904 to 1909 by the Solvay Company under the direction of X. Stainier[6] with the hope of discovering large salt deposits similar to the potash deposits of Germany. During the prospecting for coal deposits in 1905, the bit encountered some indications of salt in drillhole No. 28 at Beeringen. A campaign of drilling was then undertaken in search of salt and seven holes were sunk in the Campine region. At Neeroeteren, the Hettangian was penetrated at a depth of 2,300 feet, proving the existence of Mesozoic bituminous shales. Red beds, undoubtedly of Permian age, were also encountered, showing that the Zechstein sea extended, in all probability, to the northern border of the Brabant uplift. The test also proved the existence of block faulting in the Campine region, the trend of the faults being of the same general direction as found in the neighboring countries. As shown by the map (Fig. 1), a considerable subsidence has occurred between the horst of Brabant and the horst of Peel, the vertical throw being several thousand feet. The total amount of the throw is not known, as the bottom of the graben has not yet been reached by the drill.

Since there are some possibilities of salt-core structure, the possible existence of salt in the Campine region is considered at greater length. Judged by occurrences in Germany, the Zechstein formations are not salt-bearing everywhere, but mainly along the south shore of the ancient Zechstein sea. Along that shore line, the salt deposits are concentrated in the embayments produced by the subsidence of older Paleozoic formations. In the near-shore deposits of the embayments themselves, salt deposits are absent. They are found only in the deeper parts, mainly in the central portions. This is in accordance with the Ochsénius theory of formation of salt deposits by evapora-

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[6] X. Stainier, "Sur les recherches du Selen Campine," *Ann. des Mines de Belgique* (1911), pp. 117-69.

tion of marine brines in gulfs communicating imperfectly with the open sea. The Meuse valley in the Campine offers the necessary characteristics to warrant presumptions of the existence of salt deposits in the North Campine region.

OIL AND GAS POSSIBILITIES

A good potential source bed is represented by the Hettangian formation of Jurassic age, which has considerable horizontal extent. Although not very numerous, oil indications exist. In the drilling operations at Woensdrecht, strata yielding a strong bituminous odor were encountered just above the Carboniferous limestone. In the Dutch Limbourg, a test made at Ratum demonstrated the existence of petroliferous impregnations in Carboniferous sandstones. Farther north in Holland, an oil seep has been known at Haarlem since the Middle Ages. Medicinal oil has been extracted from it and sold even in modern times under the name of "Huile d' Haarlem." To the writer's knowledge, the source of the oil has not been determined.

The preceding considerations establish the fact that the Campine region of Belgium may be regarded as a prospective petroliferous province. However, the existence of commercial oil pools has not yet been ascertained. Before any drilling operations are carried on, preliminary surveys by modern geophysical methods of prospecting should be applied to the region. A magnetic survey in the northern parts of the provinces of Antwerp and Limbourg would probably reveal buried Cambrian hills by magnetic anomalies, and possible salt domes as magnetic lows. Since the interpretation of magnetic indications is not always reliable, further survey of the magnetic indications should be checked by the reflection seismograph.

CRETACEOUS BASIN OF MONS

Explorations for oil have been carried on recently in the Cretaceous basin of Mons. The incentive was the discovery of iridescent patches on the surface of the water at Thirieau du Sar.

Several shallow prospecting wells were drilled at the following locations: (1) Mons du Sar (Meuler farm), abandoned at a depth of 100 feet after passing oil-impregnated sand; and (2) Roeulx, abandoned at 52 feet.

The search for oil has been centralized around Houdeng-Gougnies and at the time of the investigation (1928–1929) it was believed that under the chalk at 1,700 feet there would be an accumulation of oil.

It is possible that oil may have migrated along the Midi fault from the overthrust sediments, since bituminous breccia is known to be present near Landelies about 10 miles southeast of the Cretaceous basin.

A cross section of the basin is given in Figure 4 from which it may be inferred that possible traps for petroleum are lenticular sands on the sides of the basin under an impervious cover of chalk.
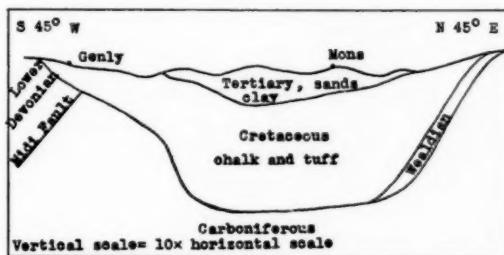
Fig. 4.—Generalized cross section of Cretaceous basin of Mons.

However, the origin of the oil in the Cretaceous basin of Mons is an open question. If the hypothesis of migration along the Midi fault should be discarded from future geological investigations, the basin must then be considered as being of too small extent to warrant the existence of commercial oil deposits.
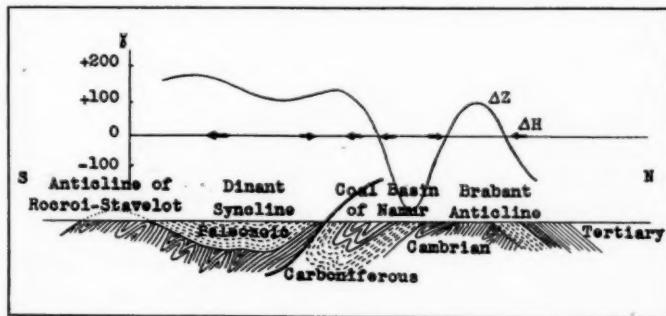
Fig. 5.—North-south cross section in Dinant basin and magnetic anomalies. After Merken.

DINANT BASIN

It is believed by some geologists and students of the Paleozoic formations of southern Belgium that oil may be trapped under the thrust fault known as the "Midi fault." This assumption is based mainly on the belief that the fault is of the low-angle thrust type, the

displacement being 25–50 miles.[7] In fact, it is possible to find locally horizontal planes of faulting in the regions of Namur, Landelies and Theux, but in the light of magnetic measurements published by Merken,[8] this assumption of the existence of a major low-angle over-thrust must be abandoned. In fact, the magnetic anomaly on the Namur syncline (Fig. 5) is very symmetrical, an indication that the deep disturbance is vertical and that horizontal thrusting is purely a local phenomenon or the after-effect of intense compression in the Basement rock and in the foreland. It is, then, fairly safe to assume that the foreland of the Midi fault does not contain petroleum in commercial quantities.

Concerning the Paleozoic of the Dinant basin, the folding is similar in intensity to that in the Appalachian Mountains, a condition which rules out the possible existence of important amounts of petroleum in the region.

BELGIAN CONGO

Three areas in the Belgian Congo have oil and gas possibilities: (1) the Coastal zone (Low Congo); (2) the Central basin; and (3) the African rift valleys.

COASTAL ZONE

Oil seeps have been known for a long time in Portuguese Angola, and in the Tertiary and Cretaceous beds along the western coast in Angola and Congo.

Two series of strata are known in the regions. The lower series is believed to be Middle or Upper Cretaceous in age and is composed mainly of sandstones, marl, and clay containing plant remains. Some of the sandstones are impregnated with bitumen at Shipanga, Mussera, and Dande. The upper series is believed to be Tertiary in age (Lower Paleocene).

No favorable structures are known to occur in the region, but it seems possible that petroleum may occur in commercial quantities.

CENTRAL BASIN

GENERAL GEOLOGY

In general, the Congo basin is filled with Permo-Triassic beds, lying on a basement of metamorphic and igneous rocks. Gneisses,

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[7] This theory has been described in detail recently by F. Kaisin in a communication to the Société Scientifique de Bruxelles, Bruxelles, 1934. See also: *La Nation Belge*, May 23, 1934.

[8] M. Merken, "Note sur la répartition du magnétisme en Belgique," *Congrès International des Mines et de la Géologie Appliquée, Section de Géologie* (Liége, 1930), p. 354.

schists, quartzites, granite, diorite, porphyry, are known to be present under the sedimentary beds. The deposition of the Permo-Triassic beds took place on an irregular surface, as may be inferred from the quartzite, diorite, and granite hills which project through the upper formations. Those beds are designated under the name Lualaba-Lubi-
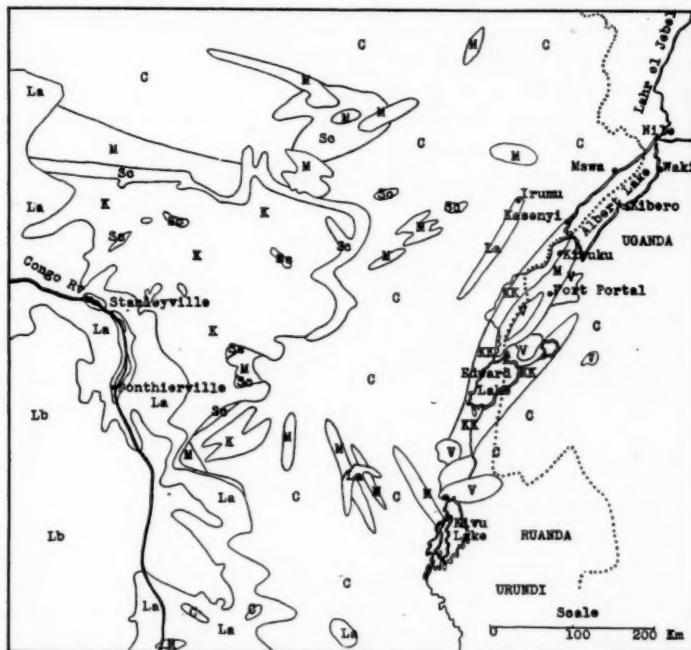
FIG. 6.—Areal geology of northeastern Congo. *Lb*=Lubilache system (Upper Triassic). *La*=Lualaba system (Upper Triassic). *K*=Kundelungu system. *Sc*=Schisto-calcareous series. *M*=Metamorphic series. *C*=Crystalline series. *KK*=Kisegi and Kaiso beds. *V*=Recent volcanic rocks.

lache formations and belong to the Karoo system of South Africa. They present considerable facies variations throughout the region. The southwest portion is underlain with sandstones and conglomerates, more than 1,800 feet in thickness, in the Kwango region. Toward the northeast the argillaceous facies are predominant and the shale formation which appears in the Kwango and Kasai valleys become thicker.

In the northeast section there are three structural basins worthy of consideration.

1. The Luena basin is underlain with shales, sandstones, and valuable coal seams.

2. The Lukuga basin is underlain with sandstones, conglomerates, shales, and workable coal layers. The thickness of the formation is here more than 2,100 feet. In this basin the deposition was accomplished on an irregular bottom and deformation took place during sedimentation.

3. The Stanleyville-Ponthierville basin (Fig. 6) is famous for its bituminous shale deposits. As the assumption of potential oil deposits in the Congo basin is based on their existence, they are here considered more extensively.

The deposits were laid down on an irregular surface of gneiss, schists, quartzite, granite, and porphyry. The following succession is represented, No. 7 being at the top, or youngest.

    7. Sandstone zone with bituminous layers at bottom
    6. Red argillite with bituminous shales
    5. Argillite and green shales containing bituminous layer of greatest thickness and extension
    4. Sandstone zone with conglomerate at bottom and bituminous shales at top
    3. Calcareous formation
        c. 1st layer (500 feet thick), öolitic limestone (dips 15° south)
        b. 2d layer (150 feet thick), dipping south
        a. 3d layer (650 feet thick), strongly folded and dipping south 22°
    2. Conglomerate and red sandstone
    1. Igneous and metamorphic rocks

It is believed that the second and third zones have a great extension in the center of the Congo basin toward which they dip slightly at a rate of 12–15 feet per mile.

The study of outcrops in the Stanleyville-Ponthierville region has proved that eleven bituminous layers are present in the region whose average of oil varies from 80 to 110 liters of petroleum per ton, diminishing toward the center of the basin.

These formations are characteristic sapropelic deposits and where deposited in a shallow interior sea or in lagoons, connected with the ocean toward the northeast. Fossils found in those beds prove them to be of Juro-Triassic age and of brackish-water origin. The following forms have been identified.

Fish: *Pholidophorus corneti*
               Peltopleurus maeseni
               Lepidotus congolensis

Entomostraces: *Estheriella lualabensis*
  Estheria
  Colobodus
  Darwinula globosa
  Matacypris passaui

The calcareous facies is observed only in the lower zone of bituminous layers, which is an indication of the proximity of the sea at the time of deposition. After deposition and folding, considerable water circulation occurred, as is indicated by calcite fillings in the cracks in the limestone.

The bituminous shales may have served as a source bed for petroleum in regions where they are buried by a considerable thickness of strata, mainly toward the center of the Congo basin.

The presence of bituminous material, as that on the surface near the Ponthierville-Stanleyville railroad is an indication of the existence of free oil in the area.

As previously stated, the general dip of the surface beds is 12-15 feet per mile in a southwesterly direction. This dip is probably sufficient to have caused the migration of oil into favorable traps. The
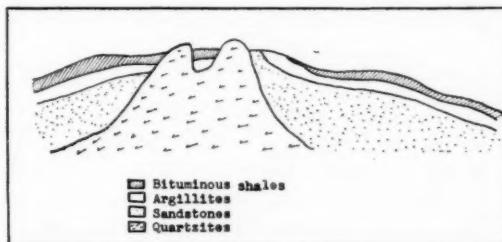
FIG. 7.—Compaction of sediments around quartzite hill.

only possible structures favorable to accumulation would seem to have resulted from compaction of sediments around "buried hills" of metamorphic or igneous rocks. G. Passau[9] gives a cross section (Fig. 7) in the Lualaba valley where the arching of the sediments is evidently due to compaction around a quartzite hill. In Passau's report, it is mentioned several times that the sedimentation of the Lualaba-Lubilache formation was accomplished on an irregular bottom and that hills of granite and metamorphic rocks have been found piercing the upper sediments. It is thus reasonable to believe that favorable buried structures could be detected by a magnetometer survey.

[9] G. Passau, "La géologie du bassin bitumineux de Stanleyville," *Ann. d. l. Soc. Géol. d. Belgique,* Vol. 45, Annexes (1921-22).

AFRICAN RIFT VALLEYS

This region comprises the zones of subsidence occupied by the lakes Albert, Edward, Kivu, and Tanganyika and is probably the most promising region for substantial oil production in the Belgian Congo, but its topographic and geographic situation makes it less attractive than the two preceding regions.

Considerable interest has been attracted recently to the Semliki valley in the Lake Albert depression, an extensive study of which has been made by E. J. Wayland[10] for the Uganda Geological Survey.

The region known as the African rift valleys is tectonic in origin. Subsidence of the floor occurred in Upper Tertiary time and was a slow and continuous process. Sediments eroded from the surrounding mountains filled the depression, forming thick deposits of shallow-water sediments. Although the connection with the ocean has not been proved, the formations are brackish in origin and the presence of gypsum and salt indicates repeated partial desiccation.

STRATIGRAPHY

Two series separated by unconformities are as follows.

Kaiso beds
Unconformity
Kisegi beds
Unconformity
Crystalline complex

The Kaiso beds are a series of considerable thickness (1,000–2,000 feet). They are mainly argillaceous in character with intercalations of sands and sandstones. They contain ironstone with many fossils, including fish, mammals, reptiles, and shallow-water mollusks. They also contain gypsiferous clays, which may be indicative of aridity.

An unconformity separates the Kaiso beds and the Kisegi beds, the latter being deposited supposedly on the Crystalline complex. The sediments are probably Miocene or late Oligocene in age.

The Kisegi beds are shallow-water sediments deposited on a sinking bottom. They show false beddings and contain arenaceous and conglomeratic facies.

SURFACE INDICATIONS OF PETROLEUM

Oil seepages.—Three important seepages exist in the region. One was discovered at Mswa on the Congo side of Lake Albert, and the

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[10] *Op. cit.*

two others, which constitute regions of abundant seepages, are at Kibero and Kibuku on the Uganda side. An exposed oil sand is also reported to be present at Kibuku. In 1862 bituminous materials were reported floating on the Tanganyika Lake.

Mud volcanoes.—An extinct mud volcano has been observed between Kisegi and Nybroge. An active mud volcano is known in the region north of Lake Edward, which is partly filled with Kaiso and Kisegi formations. The volcano is situated on the Kaiso beds, which are at a higher elevation than in the Semliki valley.

Gas seepages.—Gas seepages are known at Kibero, but the composition of the gas is not known to the writer. From native reports it is known that subaqueous explosions occur in Lake Albert halfway between Kibero and Kasenyi, which is on a line of fracture. Similar explosions have been reported on Lake Kivu, producing fumes of kerosene and large quantities of mud and oil, killing many fish.

Not many oil seepages are known probably because: (1) the Kaiso beds are unconsolidated and impervious, thus sealing all cracks which have been produced; (2) no important fractures are present in the sedimentary beds; and (3) traps are produced near the metamorphic cliffs on account of scarpward dips of the sediments.

SECONDARY INDICATIONS OF PRESENCE OF OIL

Although the function of salt in oil formations is a debatable question, it is interesting to note that the presence of salt is reported at Kibero and at Katwe. Kibero is considered the great salt center of Uganda, where a native industry has been developed, although the individual salt beds are thin. Katwe is another great native salt center at the north end of Lake Edward, which is one of the several saline lakes in the Uganda region.

SIGNIFICANCE OF AFRICAN RIFT VALLEY PETROLEUM

The origin of Lake Albert petroleum is not well known and it is an open question as to whether the source beds are situated in the Kisegi beds or in the Lualaba-Lubilache series which is believed to exist below the Kisegi beds. Although the Lualaba-Lubilache series has not been found in the Lake Albert depression, it is probably present there because the Irumu basin (40 miles west of Kesenyi) is filled with sediments of the same formation. Furthermore, black shales are present in the Irumu basin which have been correlated with the bituminous shales of the Stanleyville-Ponthierville basin.

FAVORABLE STRUCTURES

Different tectonic movements have folded and tilted the sedimentary deposits of Lake Albert. One well defined structure is known as the Waki dome (on the Uganda side) with dips varying from 68 to 155 feet to the mile. From borings made around the dome it appears that the surface structure reflects the subsurface structure very closely.

The writer does not know of any favorable structure on the Congo side. The north dip of the Kaiso beds is indicative of a possible migration of the oil from north to south and investigation between Semliki River and the East Cliffs of the mountain range is advisable.

FLUID MECHANICS OF SALT DOMES[1]

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ABSTRACT

A fluid mechanical hypothesis for the formation of salt domes is presented, for which the basic assumptions are: (1) that the prime motive force for the formation of domes is the density difference between the salt and the surrounding sediments; and (2) that both the salt and the surrounding sediments behave as highly viscous liquids and slowly flow through long geological time.

A simple analysis of the behavior to be expected under the above assumptions shows that a "peripheral sink" will be formed. This will cut off the supply of salt flowing into the dome but this cut-off does not depend on the salt being actually pinched off by the meeting of rocks originally above and below the salt. It may occur at any stage in the development of the peripheral sink, depending on the strength or viscosity of the overburden.

Expressions for the volume relations and relative dimensions of the dome are given in terms of the thickness of the salt and radius of the peripheral sink. Several numerical examples are tabulated.

A series of qualitative experiments show the flow, under a wide range of relative viscosities, of two liquids of different densities with the lighter liquid originally below the heavier liquid. The experiments illustrate the modifications of the flow produced by the peripheral sink and the manner in which the cut-off by the peripheral sink is controlled by the relative viscosities of the two liquids involved.

A series of diagrams is presented to show the hypothetical history of the formation of domes by fluid flow with the further assumption that the flow takes place in a time comparable with the time of deposition of the overlying sediments. From these diagrams it is evident that some of the most striking geological features of salt domes, such as overhang, rim synclines and down-faulted blocks next to the salt are natural consequences of the fluid hypothesis. Also the wide range in form and volume of salt domes in the Gulf Coast and in the interior of Texas and Louisiana, as indicated by the wide range in gravity effects which they produce, can be reasonably accounted for by the fluid hypothesis outlined.

INTRODUCTION

In the past discussions of the mechanics of salt domes, it seems to have been a general assumption that the salt behaves as a plastic material while the surrounding and overlying sedimentary rocks behave as relatively rigid solid materials. This is shown by various model experiments which have produced structures similar to those which salt domes probably have in nature. Nearly all of these experiments have involved the movement of a relatively plastic or fluid material under externally applied forces or pressures and within relatively rigid constraints. Of the experiments of this kind, reference may be made to those of Torrey and Fralich (1),[3] Link (2), and Escher and Kuehner (3).

In all of these experiments there are two elements for which it is difficult to see definite counterparts in the probable movements and mechanics of salt-dome formation in nature. These two elements are: (1) an externally applied motive force which is relatively enormous compared with the size and strength of the other elements of the experiment; and (2) boundaries or constraints which are almost perfectly rigid or infinitely strong compared with the other elements of the experiment. Examples of such boundaries are: the hole through which grease was forced by Torrey and Fralich; the rigid plug in many of Link's experiments; the steel plate and "chimney" used by Escher and Kuehner.

The following pages present the conception that the formation of salt domes is essentially the movement of very viscous fluids under gravitational forces. A simple mathematical formulation of the forces and movements and some simple experimental demonstrations are given. These may be of particular interest in connection with a recent paper by Barton (4) in which there is set forth a theory of salt-dome formation by "isostatic down-building." Barton's theory has several points of similarity with the fluid hypothesis which is here offered.

The fluid conception has developed gradually with the writer in connection with interest in salt-dome forms from the analysis of torsion-balance gravity surveys over domes in the Gulf Coast, northeast Texas, and north Louisiana. The hypothesis of the formation of domes as the result of fluid movement under gravitational forces is the natural result of the indications that, for all domes for which data are available to the writer: (1) the salt is lighter than the surrounding sediments, as shown[4] by gravity surveys; and (2) the domes all have

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[3] References are to the bibliography at the end of this paper.

[4] A few domes do not show negative gravity anomalies, but the presence of light

a circular or at least a generally rounded form, suggesting that their form is controlled by yielding and flow of the surrounding material and not primarily by fracturing.

Evidence on the first of these indications is fairly definite and quantitative; on the second (flow of salt and sediments) it is highly qualitative.

DENSITY DIFFERENCE BETWEEN SALT AND SURROUNDING SEDIMENTS AND RESULTING GRAVITATIONAL MOTIVE FORCE

Torsion-balance surveys in the salt-dome areas of the Gulf Coast, northeast Texas, and northern Louisiana have given very definite evidence that the salt is lighter than the surrounding sediments.

The density contrast between the salt and surrounding sediments is variable. This contrast increases with depth because there is an increasing density of the deeper sediments, while the salt density is probably nearly constant. From calculations in connection with the interpretation of salt-dome gravity anomalies, from actual density measurements and from a quantitative modification of the compaction theories of Hedberg (5) and Athy (6), it is probable that Gulf Coast sediments increase in density with depth approximately as shown by curve *A* of Figure 1.[5] This density distribution is in close agreement with densities derived from similar considerations by Barton (4), (7), (8), (9). The density of the salt is considered as constant at about 2.2 (curve *B* of Figure 1). Thus, in the Gulf Coast, below a depth of about 2,000 feet, the sediments are heavier than the salt. At shallower depths the sediments are lighter than the salt. The possible differential pressure due to these density differences is shown by curve *C*. This curve shows the difference between the weight of a column of sediments from the surface to a depth of 20,000 feet[6] and the weight

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salt is reasonably possible in these domes, for the negative gravity effect is slight, due to small volume of the salt, and is completely or greatly obscured by positive effects of heavy cap rock.

[5] The part of this curve below a depth of about 10,000 feet is extrapolated without any definite control. The control which might be expected from gravity calculations is very weak because of the fact that, when horizontal dimensions are no greater than the depth below the surface, it is almost impossible to distinguish between a large mass with a small density contrast and a smaller mass with a large density contrast. Only the mass anomaly (product of volume and density contrast) can be definitely determined.

[6] The torsion-balance surveys have given a rough estimate of the depth from which the domes rise, that is, the depth of the original or mother salt layer. This estimate is based on detailed calculations of salt-dome structures to fit torsion-balance gravity pictures. From such calculations we estimate the depth of the mother salt layer as about 20,000 feet in the Texas Gulf Coast. This is in general agreement with estimates on the same basis made by Barton (7), (8), (9).

of a column which includes salt from a depth of the abscissa of the curve down to a depth of 20,000 feet. This is, therefore, the differential pressure tending to cause salt to move horizontally into the base of a dome at a depth of 20,000 feet as a function of the depth to the top of the dome.[7] With a possible magnitude ranging from a few hundred up to 1,400 pounds per square inch, it seems reasonable that the gravitational force due to the density difference between salt and sediments is sufficient to cause a slow movement of salt and surrounding sediments during long geological time.

POSSIBILITY OF FLUID BEHAVIOR OF SALT AND OF SURROUNDING ROCKS

There are several experiments showing that salt will flow but there is some question as to the applicability of these experiments to the flow of salt in domes. Van Tuyl (10) has demonstrated the flow, under very high pressures (11,000 to 29,000 lbs./sq. in.), of a small column of rock salt in a closely fitting cylinder. Rinne and Hoffman (11) measured the flow of salt by the penetration of a cone loaded with a constant weight. Flow was measured as function of both time and temperature. Qualitatively the temperature effect was similar to that obtained by Van Tuyl. The pressures used in both these experiments were many times higher than those available due to density differences in the Gulf Coast (curve *C* of Figure 1).

In discussions of salt domes it is often stated that "salt becomes plastic under the pressure of the overburden, and flows" or words to that effect. The idea seems to be that the salt is not strong enough to maintain a void or cavity when subjected to the pressure of the overburden, and it is apparently in this sense that Van Tuyl applies the results of his experiment to the question of salt flowage in domes. To the writer, the real question seems to be whether salt would flow with a greater or less pressure *difference* when under a high ambient pressure. In other words, if a piece of salt were surrounded by a hydrostatic pressure corresponding to the depth of burial in domes (say a pressure of 20,000 pounds per square inch), would its elastic limit, with regard to stresses continued over very long time, be increased or decreased? Unless the elastic limit (minimum stress which will cause a permanent set or flow) is reduced by an ambient pressure, there is no greater reason for salt to flow under a heavy overburden than under a lighter overburden excepting to the extent that the weight of the overburden can contribute to the *differential* pressure within the

[7] Curve *C* is an approximate quantitative presentation of the same hypothesis which is outlined qualitatively on pages 1037 and 1038 of Barton's paper (4).

DENSITY CONTRAST AND
DIFFERENTIAL HYDROSTATIC PRESSURE
AT BOTTOM OF SALT COLUMN
TEXAS GULF COAST

FIG. 1
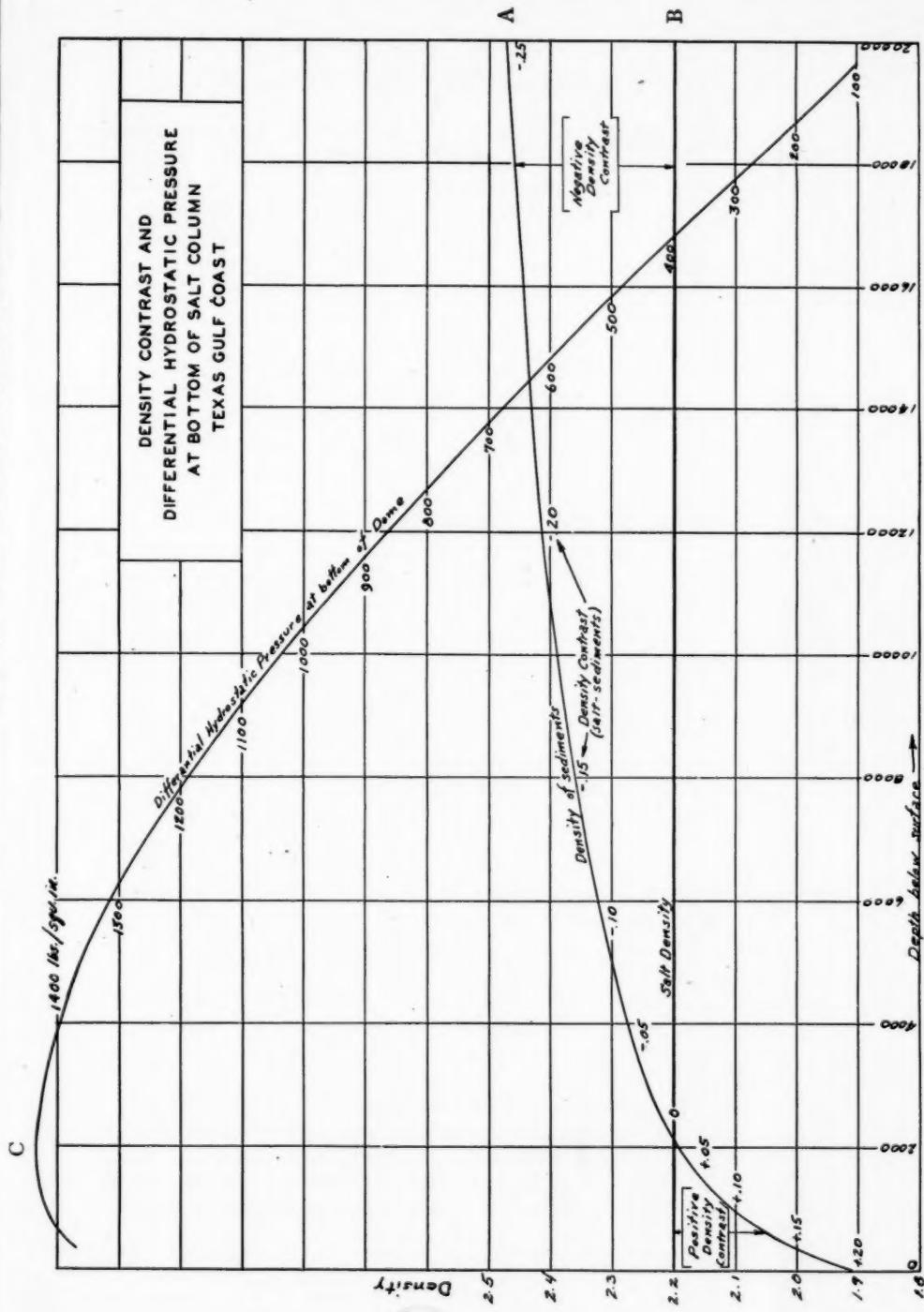
salt. An experiment (13) on marble cylinders indicates an increase of strength and elastic limit by hydrostatic pressure, but the writer knows of no experiment of this kind on rock salt. It would probably not be difficult to devise such an experiment excepting that there seems to be no way to simulate the very slow movements which may result from the application of stress over millions of years and which might not be detected in laboratory experiments continued for any reasonable length of time.

Van Tuyl (10) has suggested that water may cause a lubricating action so that the salt flows under lower pressures than might otherwise be expected. There is some evidence against this suggestion. Joffé (12) showed that water greatly increased the strength of rock-salt crystals and says that the plastic bending of rock-salt crystals in water is due to their increase in strength. However, the exact mechanism by which water makes rock salt plastic is not yet clear and has been the subject of much controversy. A review of the various theories and many references to work on this subject are given in connection with recent work by Barnes (14), (15) and Smeckal (16). Apparently the water makes a single salt crystal plastic, but as soon as the crystal is deformed its strength is greatly increased by "cold working."

The writer tried an experiment of extruding rock salt in a simple die composed of a 7/8-inch piston fitting into a cylinder with a 3/8-inch hole in the other end. Dry rock salt could be extruded from the 3/8-inch hole. However, when the salt was wet, no extrusion resulted by the exertion of all the force available (a 15-ton arbor press or approximately 50,000 lbs./sq. in.) and the wet salt sample formed an extremely hard strong cake. It seems probable that this case, which involves an aggregate of crystals, is somewhat different from the plastic bending of a single crystal. Probably the flow (or the extrusion) of a crystal aggregate consists largely of the motion of individual crystals over each other and the water tends to prevent this motion by sealing the individual crystals together.[8] If water makes salt strong, as indicated by this experiment, we may have an explanation for the fact that salt in domes which are mined is very dry. If the salt were wet it would be so strong, perhaps, that it would not flow into the domes.

There are several lines of evidence showing that hard rocks will flow under small stresses maintained for long times. Bingham (17) calls attention to the deformation of tombstones under their own weight in a cemetery in Washington, D. C., and quotes several in-

[8] This statement is largely based on recent oral discussion with Wheeler P. Davey.

stances of rock flow from ancient structures in the old world. In an old cemetery in Richmond, Virginia, the writer has noticed a pronounced concavity of tombstones which consisted of horizontal slabs mounted on brick pillars at the four corners. Slow flow and "elastic after effect" has been determined on bars of rock cut from the coal measures of England (18). Bingham and Reiner (19) have shown that long slender bars (about 1 inch square by 33 inches long) of thoroughly cured cement mortar bend appreciably under their own weight in a few months. Flow of marble slabs, probably from forces arising from diurnal temperature changes, has been noticed in a cemetery in Havana, Cuba (20). All the evidence quoted on the flow of rocks shows only small deformations, but they were caused by small forces (in most cases, of the order of the weight of the rock) and for times which are infinitesimal in comparison with geological time.

Geological evidence on the time during which salt domes have been rising is not definite excepting in a very few cases and there seems to be no definite evidence against long continued movement of the domes. Barton's (4) conception that the movement may have been essentially continuous throughout the time of deposition of the overlying sediments is entirely consistent with the fluid hypothesis for the formation of domes. If domes have been slowly rising (relatively, not necessarily actually) throughout Tertiary and perhaps part or all of Cretaceous time, an enormously long time is available (of the order of 100 million years) for slow flow of the rocks (and salt) under the gravitational forces due to the density differences. It might be assumed that rocks are thousands of times stronger than Bingham and Reiner's (19) concrete bar and that a similar bar of rock a yard long would sag under its own weight by a thousandth of an inch in a hundred years. If such a deformation continued, the bar would sag a foot in only 1,200,000 years and would be more sharply folded than the rocks around salt domes. Yet we have called on only a small fraction of the conceivably available time in which slow rock flowage might occur.

FLUID MECHANICAL THEORY OF SALT-DOME MOVEMENT

If both salt and sediments behave as highly viscous liquids the system will be inherently unstable because a heavier liquid will be above a lighter one. Any initial irregularity will tend to start the flow. It may also be assumed that an initial irregularity is produced by some tectonic movement so that we have initially a condition such as in Figure 2-a, with an initial uplift of height d. Let us now consider what we should expect if the salt and sediments flow like viscous liquids.
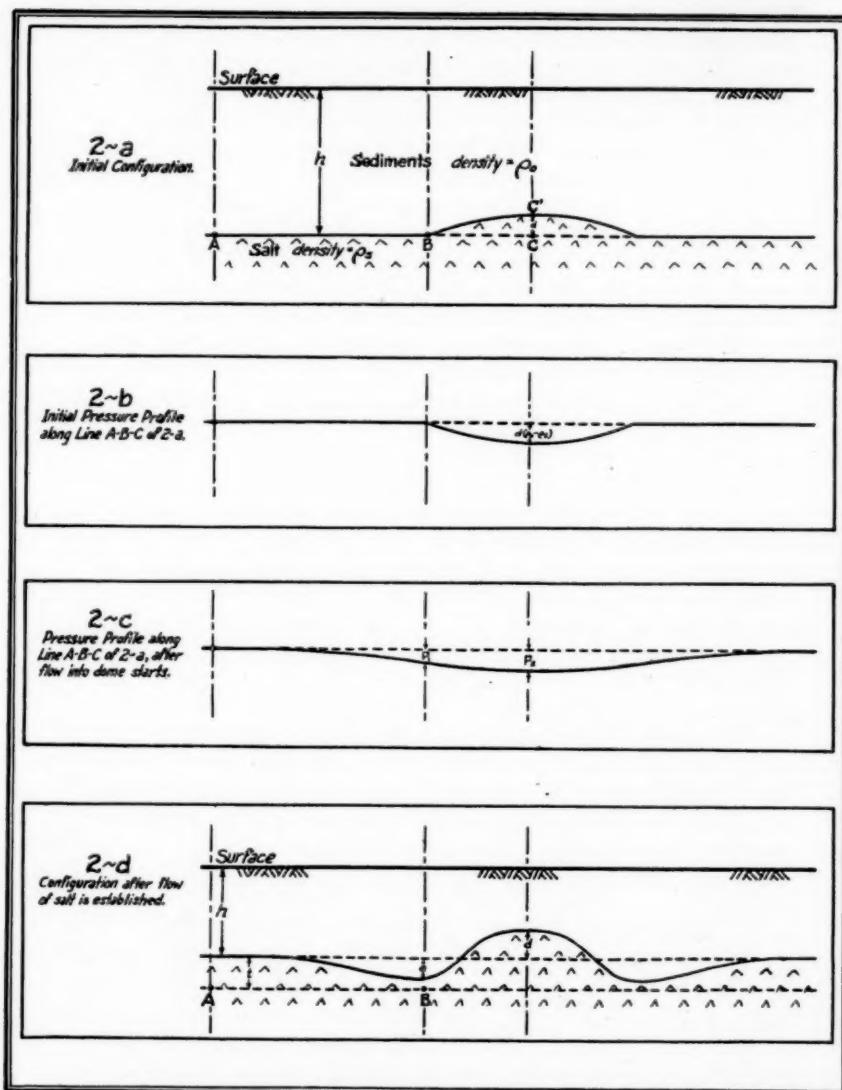
FIG. 2

Let the height of the overburden over the undisturbed salt be h, the density of the overburden be e_0 and the density of the salt be e_s. The pressure at the three points A, B, C, on a horizontal line will be:

$$e_0 h, \; e_0 h, \text{ and } e_0(h-d)+e_s d. \tag{1}$$

A pressure profile at this stage will be somewhat as in Figure 2-b and there will be a deficiency in pressure at point C which amounts to $d(e_0-e_s)$.

Due to the pressure difference from point B toward point C, there will be a tendency for the salt to flow and for the pressures to equalize along the horizontal line A, B, C. If there is no movement of the overburden, and the pressures become equal along this line, there will be an upward force on the sediments at point C' which will approach the magnitude $d(e_0-e_s)$. This is the buoyant force tending to cause the dome to rise.

Now let the overburden move under this buoyant force. The pressure at C will be reduced and the salt will tend to flow in from the surrounding area. When this flow is established, there will be a pressure drop, P_1 from A to B due to the flow and the pressure profile along line A, B, C, will be somewhat as in Figure 2-c. The magnitude of the pressure drop P_1, due to the flow, will depend on the velocity of flow, the viscosity of the salt, and the geometry of the system. There will be a further drop from B to C so that the total "velocity head" from the region of no flow to the center of the dome is P_2 and P_2 must be always less than $d(e_0-e_s)$ if there is any flow of material into the dome.

Table I shows, for each of the three points A, B, and C', in Figure 2-a, the following: (1) the pressure at the top of the salt, (2) the weight of the overburden, and (3) the difference between (1) and (2) which is the net pressure difference at the interface tending to cause vertical movement.

TABLE I

Point	Pressure at Top of Salt	Weight of Overburden	Pressure Difference	
A	$e_0 h$	$e_0 h$	0	
B	$e_0 h - P_1$	$e_0 h$	$-P_1$	$\Big\} (2)$
C'	$e_0 h - P_2 - e_s d$	$e_0(h-d)$	$d(e_0-e_s)-P_2$	

Thus at point B, the vertical force is downward and at point C' it is upward (because $d(e_0-e_s)$ must be greater than P_2 if any material flows into the dome). If the overburden moves (flows) under these vertical forces, there will be a configuration somewhat as in Figure 2-d, and there will be developed a syncline or sink in the top of the

salt which will surround the base of the dome. This will be referred to as the "peripheral sink."

Consider the pressure at points A and B on a horizontal line in the salt and let e represent the drop of the peripheral sink (Figure 2-d):

At A, the pressure is $P_a = e_0 h + e_s t$

At B, the pressure is $P_b = e_0(h+e) + e_s(t-e) - S$.   (3)

The term S is introduced because the rocks will not behave as perfect liquids, but will have a certain viscosity or perhaps a definite strength[9] which will prevent the overburden from dropping immediately into the peripheral sink. Thus the term S represents and includes all factors which contribute to the resistance which the rocks offer to downward deformation above the point B.

From equations (3) the pressure difference tending to cause horizontal movement along the line $A - B$ (Fig. 2-d) is:

$$P_a - P_b = -e(e_0 - e_s) + S.$$ (4)

Thus, unless the overburden resists the tendency to drop (that is, the term S is greater than the term $e(e_0 - e_s)$) the pressure difference will be negative and the flow will be outward from the center of the peripheral sink. The surprising conclusion is reached that *any flow of material into the dome from the area outside the bottom of the peripheral sink depends on the viscosity or strength of the overburden (the term S).* This means that unless the overlying rocks have a definite strength or viscosity, flow of material into the dome will be effectively cut off long before the rocks above and below the salt actually come together. Any development of the dome after this time will be a modification of the form of the material then within the peripheral sink.

Any tensile strength of the sediments will also tend to support the material over the peripheral sink and thus give an added resistance to the downward movement and increase the term S. In some cases, the resistance of the overburden to dropping may be such that the pressure difference $(P_a - P_b)$ remains positive until the overburden drops enough to reach the rock below the salt. In this case the flow of the salt into the dome would finally be cut off by the actual meeting of the rocks which were originally above and below the salt.

VOLUME RELATIONS

There are certain general relations between the volume of the salt in the dome, the height to which the dome can rise, the thickness of

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[9] By "strength" is meant the property of resisting finite stress without any movement (excepting true elastic deformation) even when the stress is continually applied throughout a considerable geological time.

the original salt layer, and the "radius of action" from which the salt flows into the dome.

In Figure 3 the configuration of the salt before the supply is cut off by the peripheral sink may be given by the solid line. For analytical simplicity this configuration may be approximated by the straight, dashed lines where the uplifted salt is represented by an equivalent frustum of a cone. Also, it may be assumed that the final form of the dome is a vertical cylinder as indicated on the diagram. The notation for this diagram is as follows:

a = radius of flat part of equivalent dome (frustum of cone)

b = radius of uplifted part of salt (radius of base of equivalent frustum)

c = radius of bottom of peripheral sink

r = outer radius of action or limit from which salt flows toward dome

R = radius of final cylindrical dome

H = height of final cylindrical dome

h = height of equivalent dome (frustum of cone)

d = depth of peripheral sink at time flow is cut off

t = thickness of original salt layer

v = volume of final cylindrical dome

v_1 = volume of uplifted part of dome inside radius b (volume of equivalent frustum)

v_2 = volume of peripheral sink inside radius c

v_3 = volume of peripheral sink outside radius c

The three volumes, v_1, v_2, and v_3, are given by

$$v_1 = \pi/3 \; h(b^2 + ab + a^2)$$
$$v_2 = \pi/3 \; d(2c^2 - bc - b^2)$$
$$v_3 = \pi/3 \; d(r^2 + rc - 2c^2)$$

At any time until the supply of salt is cut off by the formation of the peripheral sink, the equation will be $v_1 = v_2 + v_3$ or

$$h(b^2 + ab + a^2) = d(r^2 + rc - bc - b^2). \qquad (5)$$

Considering that the configuration approximated by the dashed lines in the diagram is that at which the supply of salt is cut off by the peripheral sink, the form of the dome at this stage can be expressed in terms of ratios of certain elements of the dome. It is convenient to express the different radii in terms of the radius, b, of the base of the uplifted part of the dome at the time the supply is cut off by the peripheral sink. To do this, let:

$$a/b = q; \; r/b = m; \; c/b = n. \text{ Also let } d/t = p.$$
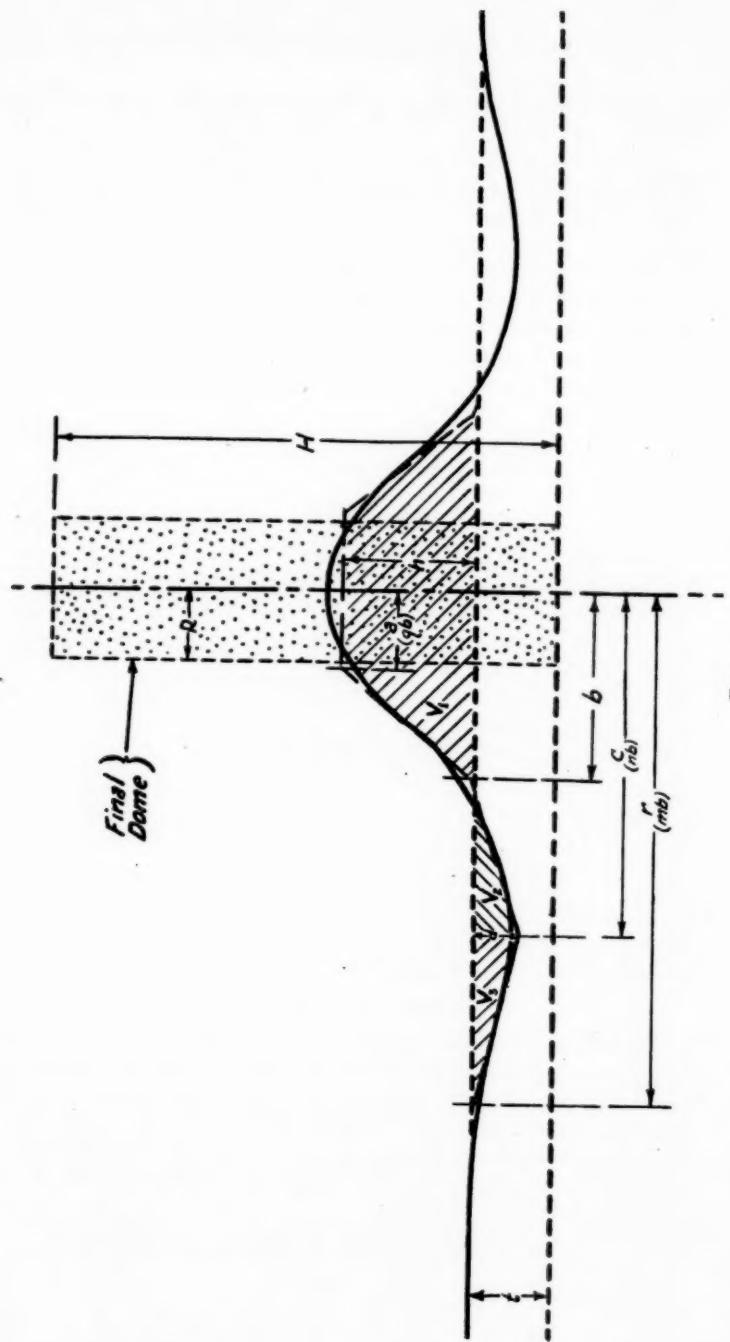
Fig. 3

Equation 5 can now be written as:

$$h(1+q+q^2) = pt(m^2+mn-n-1)$$

from which,

$$h/t = \frac{p(m^2+mn-n-1)}{1+q+q^2}. \tag{6}$$

The ratio h/t is a measure of the height to which the dome will have risen when the salt supply is cut off by the peripheral sink. A few values for the ratio, h/t, under various assumed configurations are given in Table II.

TABLE II

Case	p	m	n	q	h/t
1	¼	3	2	½	1.71
2	¼	4	1½	¾	2.10
3	1	2	1.3	¾	1.86
4	½	4	2	1	3.5

Thus, in case 1 for instance, if the diameter of the approximately flat part of the dome is 1 mile ($a=\frac{1}{2}$ mile), the diameter of the base of the dome is 2 miles ($b=1$ mile), the peripheral sink is 2 miles from the center of the dome ($c=2$ miles), the limit of the "radius of action" is 3 miles from the center of the dome ($r=3$ miles), and strength of the over-burden is such that the supply is cut off by the peripheral sink when it has dropped $\frac{1}{4}$ of the total thickness of the original salt layer, ($p=\frac{1}{4}$) the dome will have risen a height of 1.71 times the thickness of the original salt layer when the supply is cut off.

Under the assumption that the final dome is a vertical cylinder, as indicated in Figure 3, the final height of the dome which can be formed from the salt available, after the supply is cut off by the peripheral sink, can be calculated.

The volume of the final cylinder is $V=\pi R^2 H$. The salt available to flow into this cylinder after the supply is cut off by the peripheral sink is

$$V = v_1+\pi c^2\, t-v_2$$
$$= v_3+v_2+\pi c^2\, t-v_2 \text{ (because } v_1=v_2+v_3)$$
$$= v_3+\pi c^2 t$$
$$= \pi/3\ d(r^2+rc-2c^2)+\pi c^2 t.$$

Since the volumes must be equal,

$$\pi R^2 H = \pi/3\ d(r^2+rc-2c^2)+\pi c^2 t \tag{7}$$

Again, using the expressions in terms of ratios and defining the ratio of the final diameter, R, to the initial base diameter, b, as $R/b=f$, we have

$$f^2 H = pt/3(m^2+mn-2n^2)+n^2 t$$

and

$$H/t = p/3f^2(m^2 + mn - 2n^2) + n^2/f^2 \tag{8}$$

The values of H/t for certain assumed proportions at the time the supply is cut off by the peripheral sink are presented in Table III.

TABLE III

Case	p	m	n	f	H/t
1	$\frac{1}{4}$	3	2	$\frac{1}{2}$	$18\frac{1}{3}$
2	$\frac{3}{4}$	4	$1\frac{1}{2}$	$\frac{3}{4}$	6.6
3	1	2	1.3	$\frac{3}{4}$	4.9
4	$\frac{1}{2}$	4	2	1	$6\frac{2}{3}$
5	$\frac{3}{4}$	4	2	$\frac{1}{2}$	$21\frac{1}{3}$
6	$\frac{1}{2}$	4	3	$\frac{1}{2}$	$42\frac{2}{3}$
7	1	4	2	$\frac{1}{2}$	$29\frac{1}{3}$
8	$\frac{3}{4}$	3.6	1.6	.56	19.1 (for dome A, Fig. 9)
9	$\frac{1}{2}$	2.8	1.7	$\frac{1}{2}$	16.0 (for dome B, Fig. 9)

Thus for example, in case 5, if the final cylindrical dome had a diameter of 1 mile ($R = \frac{1}{2}$ mile), the radius of the peripheral sink were 2 miles, the limit of the radius of action were 4 miles and the supply were cut off by the peripheral sink when it had dropped $\frac{1}{4}$ the total thickness of the original salt layer; then the cylindrical dome would rise to a height of $21\frac{1}{3}$ times the original salt thickness. Or, expressed another way, if the bottom of the mother salt layer is 20,000 feet deep and the dome postulated reaches to the surface it would require that the thickness of the original salt layer be 940 feet. With the other factors the same, but with a stronger overburden so that the supply is not cut off by the peripheral sink until the rocks actually meet ($d = t$, or $p = 1$), we would have case 7 in the table and the required thickness of the original salt layer for the dome to reach the surface would be about 700 feet.

It will be noted that the most powerful factor in making a large value for the ratio of H/t is to have a relatively small value for f (small diameter dome) and large value for n (large radius of the peripheral sink).

EXPERIMENTS ON FLUID FLOW UNDER GRAVITATIONAL FORCES

In order to make a qualitative test of the principles previously outlined, several experiments were carried out to show the flow of two fluids having different densities, with the lower density fluid initially below the higher density fluid. The experiments covered three distinctly different cases which differ in that the relative importance of the term S (equations 3 and 4) was (1) negligible, (2) intermediate, (3) very large.
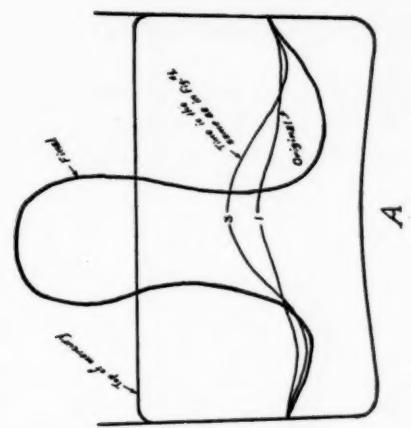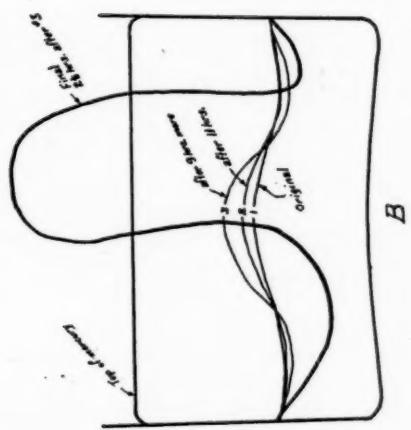
Fig. 5

Fig. 4

1. Flow of paraffine under mercury; S negligible.—This experiment was performed by pouring about 1 inch of melted paraffine into the bottom of a straight-sided glass battery jar 6 inches in diameter. An incipient dome was formed in the soft wax. After the paraffine had cooled, mercury was poured into the jar and the whole set into a thermostatically controlled oven at about 32°C. At this temperature the paraffine became soft (about like a candle on a hot summer day) and gradually flowed under the weight of the mercury. Figure 4 is a photograph of the resulting paraffine dome after it had been cut in two. The flow lines can be seen in the original cross section, but do not show in the cut. Figure 5 shows diagrammatic cross sections of the paraffine dome at various stages of its development. Section A is the cross section shown in the photograph (Fig. 4); section B is the perpendicular cross section.

Examination of the wax on the under surface revealed some details of the flow, as small bubbles in the paraffine were elongated where it had flowed and were round where there was no flow. In this experiment a peripheral sink was formed by the contraction of the paraffine as it cooled and was part of the original configuration (Fig. 5). The bubbles show that there was no flow in the area which was outside the original peripheral sink. Inside of the sink the bubbles were elongated. The bubbles thus showed that the flow had occurred entirely within the peripheral sink. This is to be expected, as the term S was practically zero with the fluid mercury as the overburden, and we would expect the pressure difference $P_A - P_B$ (equation 4) to be negative from the beginning of the flow.

2. Flow of heavy oil under thick syrup; S intermediate.—For this case, the overburden was simulated by a thick syrup with a density of about 1.4, and the salt by a heavy asphaltic crude oil with a density very close to 1.0. The models were made up in ordinary 400-cubic centimeter glass beakers. The syrup was made by boiling down ordinary Karo corn syrup until it boils at a temperature of 114° to 116°C. The beakers were filled about two-thirds full of syrup (which must be poured when hot if air bubbles are to be avoided). When the syrup was cool, a layer of oil about $\frac{1}{2}$ inch deep was poured over it. The beaker was sealed by filling to the top with paraffine. To show the flow the beakers are turned upside down. The oil will slowly rise, usually starting along the side of the beaker. By manipulating the beaker, turning it on its side or at various angles, incipient domes can be formed near the center of the beaker and of various shapes.

Figure 6 is a series of photographs of three of these models. The

pictures from stage *A* to stage *F* are successive photographs of the
same models, taken at intervals of $1\frac{1}{2}$ minutes. The syrup in No. 1
with a boiling point of 114°C. is slightly less viscous than that in Nos.
2 and 3 with boiling point of 116°C., which causes dome No. 1 to rise
more rapidly than the other two. The viscosity of the heavy crude
oil is approximately the same as that of the syrup.

In a second experiment, the oil and syrup were confined in a
rectangular glass-sided box about 10 inches wide, 7 inches deep, and
$5\frac{1}{2}$ inches high. The box is filled to within about $\frac{3}{4}$ inch of the top
with syrup, the remaining space is filled with the heavy oil, and the

FIGURE — 6.   TIME INTERVAL—1½ MINUTES
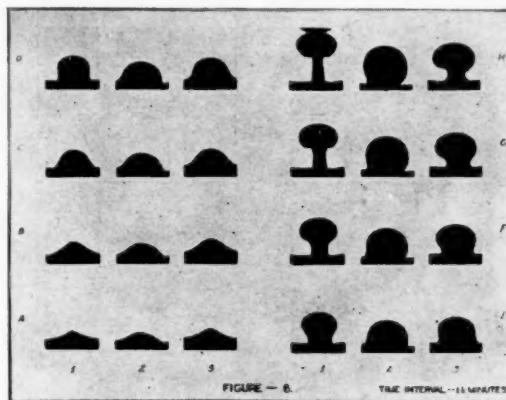
Fig. 6

box is covered with a sheet of rubber. To form domes, the box is
turned upside down and placed on blocks of wood which have pro-
jections of various forms. These projections distort the flexible rubber
and the overlying oil to form incipient domes. Figure 7 shows two
series of movements within this box. In case *A*, the movement was
initiated by a single hemispherical projection under the center of the
box. The principal result of the flow is a single large dome. The later
stages show some flow of material at the corners of the box, which re-
sults in the large bulge just under the number 12. In case *B*, the move-
ment was initiated by two projections and resulted in the formation of
two domes. There is no tendency for the oil to rise in a ridge between
the two domes. The material in the right edge of the box in the later
stages results from later flow at a corner of the box.

3. Flow of thin oil under thick syrup; S relatively large.—In this
model (Fig. 8) the salt was simulated by an ordinary motor oil, the

FIGURE — 7.

TIME INTERVAL -- 1 MINUTE

Fig. 7

FIGURE — 8.   TIME INTERVAL -- 14 MINUTES
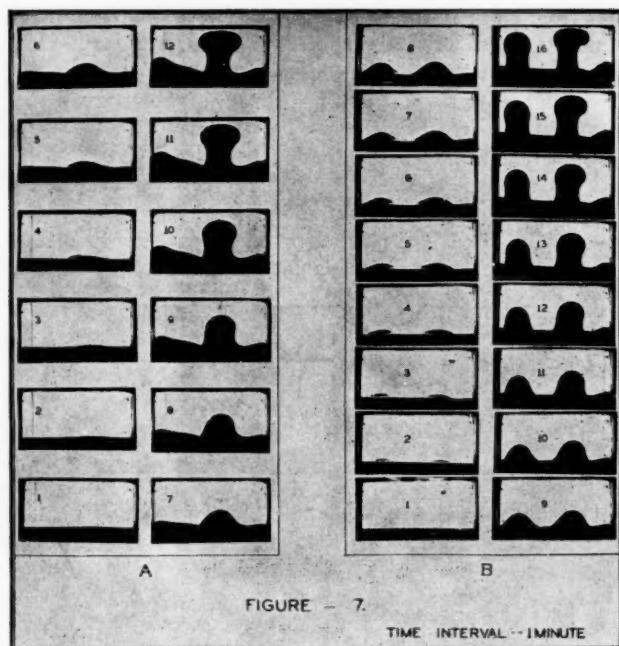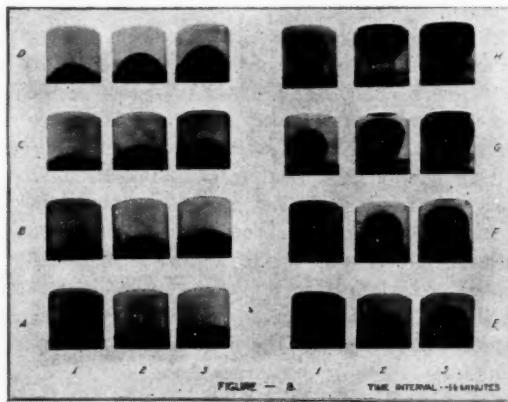
Fig. 8

sediments again by a thick syrup similar to that used in the second series. The three models are the same excepting for a different thickness of the original layer of oil (corresponding with a different thickness of the original salt layer). The original thickness is shown by a line across the lower part of the model, which was made by a rubber band placed around the beaker at the top of the oil layer before the flow started.

The character of the flow is quite different from that in case 2. Note that all the oil available is gathered up into the "dome" and that the "floor" (surface of the paraffine) is swept clean. This is to be expected as the relatively strong overburden does not collapse over the peripheral sink and the lighter fluid continues to flow under the peripheral sink into the "dome."

HYPOTHETICAL HISTORY OF THE FORMATION OF DOMES BY FLUID FLOW

The fluid theory outlined in the foregoing paragraphs is too incomplete and the fluid properties of salt and sediments are too little known to permit more than general qualitative speculation as to the probable history of domes formed under such a system of fluid mechanics. However, if these general principles are applicable, it seems reasonable that the final (present) form of the dome will depend largely on (1) the initial configuration which localized the dome (2) the thickness of the mother salt layer, (3) the strength or viscosity of the overlying rocks, (4) the strength or viscosity of the salt.

In an attempt to follow out the possible history of domes, the diagrams of Figure 9 were constructed. These assume conditions similar to those postulated by Barton (4), that is, that the time of flow of the domes is of the same order as the time of deposition of the overlying sediments. The successive dome cross sections were drawn by assuming movements in accord with the principles already outlined. The formation of the "peripheral sink" serves an important function in controlling the flow.

Now let us follow the hypothetical history of a dome under column *A*. Let the initial dome (stage 1) be formed by some sort of tectonic movement which occurs after the salt is buried, as indicated by the two overlying layers. This movement lifts the rocks (both the salt and overlying sediments) into a gentle structure without materially affecting the thickness of the salt. Now let a certain amount of flow take place between stage 1 and stage 2. During this slow flow another layer of sediments is deposited over the two which are shown in stage 1. During part of this deposition, layer 2 is assumed to have projected
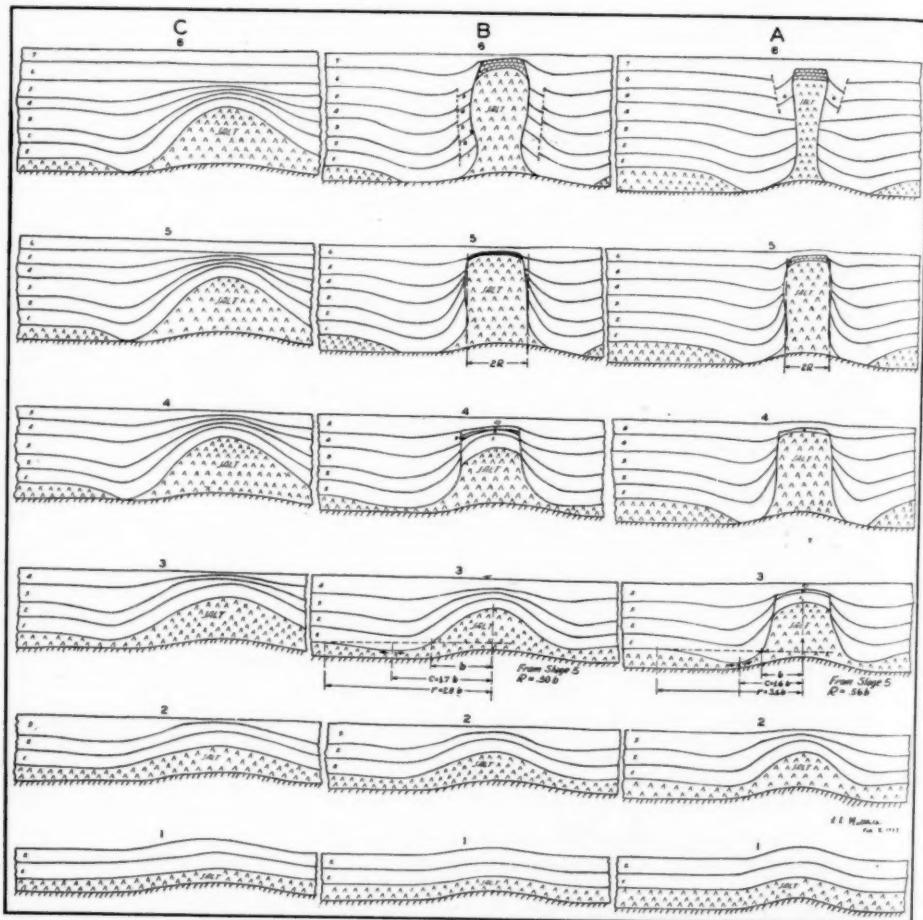
Fig. 9

as an island from the sea or to have been raised as a topographic mound so that its surface was eroded as represented by the unconformity line. As a result of this uplift and erosion, layer 2 and layer 3 will be thinner over the dome than in the undisturbed areas out from the dome. At stage 3 the salt is assumed to have risen considerably more and to have broken out and pushed ahead of it part of layer 1 by the formation of a circular fault around the dome. The fourth layer of sediments has now been deposited and again is thinner over the top of the dome than in the surrounding undisturbed areas.

At about stage 3 the supply of salt into the dome is assumed to have been cut off by the drop of the peripheral sink. Flow will now be away from the peripheral sink, as indicated by the flow arrows, and further development of the dome is at the expense of material already within the area of the peripheral sink. At stage 4 the original material over the dome is nearly removed by erosion. By stage 5 the erosion has removed the material which had been above the salt and it is now near enough to the surface to permit circulating water to dissolve some of the salt. It is probable that the cap rock would begin to form at this stage, if the cap rock is secondary and is formed either as a residue of insoluble constituents of the salt or is derived in some way from the water of an overlying sea. (The details of cap-rock formation or even the question of whether it is primary or secondary do not seem to bear any critical relation to the general mechanics of fluid flow and therefore there is no need here to enter further into a discussion of the many puzzling questions of cap-rock formation.)

As the dome rises beyond stage 3, when the supply of salt is cut off by the peripheral sink, the cross section of the salt decreases. This requires some settling of the sediments around the dome to fill the space relieved of salt and gives a tendency for the sediments to collapse. Thus, beds which were steeply upturned in stage 5 may be much less steeply upturned in stage 6. This collapse may cause material to slip downward along the dome to occupy the space thus relieved. This would tend to give down-dropped blocks close to the dome as shown in stage 6.

It is evident that as the salt rises an equal volume of sediments is displaced. The salt-dome history postulated accounts for this displacement in the following three ways: (1) by filling up the space voided by the salt around the dome (the peripheral sink) and, in the later stages, by filling the space vacated by flow of salt from the base of the dome; (2) by erosion of uplifted sediments over the dome (this material would become part of the next following layer deposited);

(3) by non-deposition of the subsequent layer due to a topographic mound (or island) caused by uplift of material above the salt.

The total volume of salt in stages 5 and 6 is shown as successively smaller than that in stage 4. This is not a necessary consequence of the fluid theory, but is a natural consequence if the salt actually reaches the surface, where it would be removed by erosion and solution. Such action might be expected because, as the motive force due to the pressure difference increases, the dome rises (curve *C*, Figure 1). Thus we would expect a comparatively rapid development at stages 4 and 5. However, the development would be less rapid at stage 6, when the cross section becomes relatively narrow, because a relatively greater deformation of the salt and sediments is required to force up a given volume of salt and any frictional forces, either at the edge or within the salt, would more effectively retard the flow.

The dome of column *B* is supposed to have been localized by an initial uplift covering a larger area, making a larger volume of salt available before the supply is cut off by the peripheral sink. Otherwise its history is generally the same as that of the dome in column *A*. The volume relieved by flow of salt upward from the base of the dome is larger, which would tend to give a greater tendency for slippage downward along the dome. For this reason, the assumed faults around the dome have been carried to greater depths.

The dome of column *C* is assumed to be formed in an area with a relatively thin original salt layer and a relatively strong series of overlying sediments. On account of this strength of the overlying sediments, the supply of salt may be assumed to be cut off by actual meeting of the rocks above and below the salt rather than by the development of a peripheral sink. At stage 4 the arch of strong sediments is assumed to have become strong enough to resist further collapse along the flanks, thus stopping or materially reducing the flow so that the rate of uplift is much less than the rate of deposition. Thus the dome is buried deeper and deeper in the later stages, producing a "deep dome."

The volume relations corresponding to domes *A* and *B* have been calculated and are shown as cases 8 and 9 respectively in Table III. The calculations are based on the approximately cylindrical dome shown in stage 5 as the "final" form and on the cut-off of supply by the formation of the peripheral sink at the configuration shown in stage 3. The ratio H/t, for dome *A* is 19.1 and for dome *B*, is 16.0. Thus, a dome of the form of stage 5 of dome *A* and with a history as indicated could reach the surface through 20,000 feet of overlying

sediments if the original salt thickness were about 1,050 feet. Under similar assumptions a dome such as stage 5 of *B* would require a thickness of the original salt layer of about 1,250 feet.

SALT-DOME GRAVITY ANOMALIES AND THE FLUID THEORY OF SALT-DOME FORMATION

On the fluid mechanical hypothesis of salt-dome dynamics, a wide variety of dome forms can result from the accidents of the initial deformation and the possibly different mechanical properties of the overlying rocks. Thus, if the salt were thick, the overlying sediments relatively soft, and the initial deformations of relatively small area, comparatively slender domes such as *A* of Figure 9 might be expected. With the same salt and sediments but with a larger area of initial deformation, a large shallow dome such as *B* of Figure 9 would be expected. A thin salt layer and strong sediments would result in deep domes, such as *C* of Figure 9. Deep domes might also exist as earlier stages of development in areas of thick salt and soft sediments. Also, we might expect a later series or "second crop" of domes to be formed of the residual salt in areas between more completely developed domes. This would be a natural consequence of flow of material away from the peripheral sinks of surrounding domes which are fairly well advanced.

The wide variety of salt-dome forms which are possible consequences of the fluid theory is matched by the wide variety of salt-dome gravity pictures which are found, especially in the Gulf Coast. Some domes have very small salt-gravity effects or have the salt effect almost completely masked by cap-rock effect (Nash). These would correspond approximately with dome *A* of Figure 9. Other domes have very large salt-gravity effects, with or without marked cap-rock effects (Blue Ridge). These would correspond with dome *B* of Figure 9. Still others have the gravity effects over a wide area but of comparatively small gravity relief, which condition is characteristic of deep domes (Sugarland). These would correspond with dome *C* of Figure 9, or possibly with later or "second crop" domes as previously suggested.

The interior domes of northeast Texas and north Louisiana differ from those of the Gulf Coast in several ways. Thus, relative to the Gulf Coast domes, the interior domes: (1) are surrounded by much older surface rocks (Eocene rather than Pleistocene or Pliocene); (2) arise from an original salt layer which is probably several thousand feet shallower; (3) may have intruded through relatively harder and presumably stronger rocks at shallower depths (the Cretaceous and

Comanche limestones); (4) are surrounded by more definitely strati-
fied and identifiable rocks so that near-surface movements due to the
domes are more definitely known and mapped; (5) cause gravity
effects which are generally, though not always, more pronounced than
those for the Gulf Coast domes.

The characteristic differences between the interior and Gulf
Coast domes can be qualitatively accounted for on the basis of the
flow theory as follows. Due to the presence of relatively strong sedi-
ments, we would expect greater resistance to the drop of the periph-
eral sink and a closer correspondence of the flow with case 3 and
Figure 8 (relatively large value of *S*) than with either of the other two
experimental cases. This would tend to draw a large volume of salt
into the dome and account for the large gravity effects. Due to the
strength of the overlying sediments, the peripheral sink would be
farther from the dome than for soft sediments; therefore relatively
wide areas of collapse and the formation of a rim syncline at some
distance from the dome would be expected. Due to the more definite
stratification such rim synclines would be more certainly recognized
than in the Gulf Coast. Also, because of the greater strength of the
overlying sediments, the collapse of the peripheral sink may have been
resisted until comparatively large forces developed and then, under
the accumulated stress, may have broken suddenly to form faults
around the dome. Slipping of the stronger blocks around the dome
when their support from below is relieved by the flow of salt from the
lower part of the dome might account for faults in which blocks near
the dome are relatively low. Good examples of such down-faulted
blocks are shown in the sections across Acadia and Vacherie (21).

GENERAL DISCUSSION

Probably the most interesting new point brought out by the fluid
mechanical concept of salt-dome formation is the peripheral sink, with
the cut-off of the salt supply which it would produce, and the geologi-
cal consequences of such behavior. Thus rim synclines are a natural
consequence of the peripheral sink. Also the collapse of the lower part
of the dome due to upward flow after the salt supply is cut off by the
peripheral sink affords a simple explanation of down-faulted blocks
near the dome. The tendency for the lower part of the dome to shrink,
as indicated by the experiments (Figs. 4, 6, 7, and 8) indicates that
overhang should be a natural consequence of the fluid mechanical con-
cept of dome formation. On the other hand, the experiments do not in-
dicate that an actual pinching off of the salt would be expected until the
entire volume of salt available (the salt within the peripheral sink at

the time of cut-off) has risen above the level of the original salt layer. Thus, we would expect a column reaching down to the original salt layer until most of the volume of salt has risen enough to be carried away at the surface. That this is the case in the Gulf Coast is indicated by gravity surveys which show effects from large salt volumes at great depths. A more direct indication is given by some of the Persian domes such as Kuh-I-Namak (23), where the salt rises to a height of 4,000 feet above the surrounding plain. To support the salt at such a height above the surrounding plain requires the buoyancy of a column reaching down to the estimated depth of the original salt layer (22,000 feet).

Alignments of domes parallel with recognized tectonic lines may or may not be expected. If the initial disturbances which localize domes are caused by movements along such trends, the resulting domes should lie along these trends. (A series of domes along a fault involving the salt might be expected.) On the other hand, the domes may be localized by very slight irregularities in the surface of the salt or by irregularities in density of the overburden, as suggested by Nadai (22). In either of these cases, it seems probable that the distribution of domes would be irregular and not governed by tectonic movements or general geological trends.

Finally, the wide range of the geophysical pictures (principally gravitational) produced by domes is readily accounted for by differences in initial form, in salt thickness, and in the character and mechanical properties of the overlying sediments.

The fluid mechanical theory offers no direct explanation of the fact that salt domes are not always found where there are thick salt deposits, for example, in West Texas, Kansas, Michigan, and New York. The following suggestions have been offered at various times in the discussion of this problem.

1. The known salt deposits where there are no domes are covered by relatively thin overburden. This suggests that a minimum overburden may be required to make the salt plastic. If this were true, a dome would not begin to develop until a minimum cover had been deposited over it. An experiment such as that previously suggested (page 1178) would possibly give definite indications on this point.

2. The possibility of dome formation may be governed by the competency of beds overlying the salt, and domes may form only if incompetent beds are immediately above the salt, such as is generally the case in areas where domes are known. If a salt series were overlain by a strong competent bed, domes might not be expected. The salt-dome areas of northeast Texas and north Louisiana seem to

be an exception to such a rule, as the salt is overlain by Cretaceous and probably Comanche limestone. However, if competent beds overlie the salt it may be possible for these beds to be locally broken or strongly uplifted and the salt to be squeezed into such uplifts. Thus, in their earlier stages the domes may be largely the result rather than the cause of uplift, but their later development may be governed by the principles of fluid mechanics here outlined.

DISCUSSION

D. C. BARTON: This is one of the most interesting papers on salt domes which I have heard because Dr. Nettleton has produced by experiment some domes that actually look like salt domes. With the other experimental 'salt" domes you have had to stretch your imagination to believe that they were salt domes.

L. L. NETTLETON: The black material rising up to form the domes is a very heavy asphaltic crude oil. It is about as stiff as ordinary honey. The viscosities of the oil and of the overlying syrup are about the same. The density of the oil is very close to unity; the density of the syrup is about 1.4.

D. C. BARTON: Here you are dealing with true fluids. Have you carried your experiments further so that your fluid will simulate the actual conditions in nature?

L. L. NETTLETON: I have made practically no experiments other than those with simple fluids. One model (in a glass beaker) was made with a thin layer of paraffine in the syrup, but was not very successful because the layer either was broken up in trying to place it or was so thick that the oil would not break through it. A great variety of complicating factors could be introduced, but would probably require models on a larger scale than any I have attempted. I would, of course, like to see such experiments continued in some geological laboratory. We have no intentions at present of making more elaborate experiments than those shown.

J. L. RICH: I would like to ask Mr. Nettleton whether he can give us any suggestions as to the factors which may be responsible for forming salt domes in one area and not in another. For example, why should there be numerous salt domes along the Gulf Coast and none at all in the Permian Salt Basin of western Texas? Is it a matter of a certain limit of pressure being required before the flow can start, or might perhaps temperature caused by deep burial be a factor?

L. L. NETTLETON: Suggested factors which might cause salt domes in one region and not in another are:

1. Competency of the overlying beds. In most of the known salt dome areas, overlying rocks are relatively soft and unconsolidated. Perhaps if salt is overlain by competent rocks which strongly resist deformation, the small stresses due to small tectonic deformation or accidents of deposition are not enough to cause salt to flow. With larger tectonic movements competent rocks may be broken and allow the salt to rise through them as seems to have occurred in the north Louisiana salt dome area.

2. Possible moisture content of the salt. The simple experiment mentioned (page 1178) indicated that dry salt may flow more easily than wet salt.

Perhaps the salt in salt-dome areas is very dry as is indicated by the dry salt in domes which are mined. In salt basins without domes the salt may have a higher moisture content and be strong enough so that it does not flow.

3. There may be a limiting overburden or pressure before flow can start. If this is so, the viscosity of salt should decrease under pressure (page 1178). So far as I know, no experiments bearing on this point have ever been made.

4. Temperature caused by deep burial may be a factor. Experiments by Van Tuyl (10) and by Rinne and Hoffman (11) indicated that salt flows more easily as the temperature is raised.

PAUL WEAVER: I think we ought not to overlook the fact that the salt domes in Alsace Lorraine show indications of having been formed when there was a very small overburden. Results of geophysical work indicate that those domes probably began to form when the depth was only 1,500 feet. It seems to me the question as to cause of domes forming cannot be referred to question of depth of burial, because these Alsace domes formed under very shallow overburden.

H. D. MISER: Several members of the Geological Survey have carried on detailed work in southeastern Utah during the last several years and they and other geologists have found an area of Pennsylvanian salt in what is known as the Paradox formation. The Paradox formation is revealed on several anticlines both in Utah and Colorado. The basin of salt deposits was described in an Association paper last year by Messrs. Baker, Dane, and Reeside. When Sidney Paige descended the Cataract Canyon of the Colorado River in Utah in 1921, he observed greatly disturbed rocks in association with gypsum at some places in the canyon. The field relations immediately suggested to him the presence of salt domes in that portion of the Colorado Plateau. A subsequent study by E. T. McKnight of the near-by portion of the region bounded by the Green and Colorado Rivers and the D. & RGW. Ry. has brought to light an interesting structural feature that appears to me to be a very excellent example of a salt dome of the type displayed here this afternoon by Mr. Nettleton. The salt-bearing strata in the Paradox lie beneath about half a mile of resistant rocks. In this dome, which is known as the Upheaval dome, there has been an initial uplifting of the rocks and the circular anticline is surrounded by a moat or syncline.

L. L. NETTLETON: It is possible that the Colorado and Utah domes might have been initiated simply by erosion. Is it not true that those domes are in the bottoms of canyons?

H. D. MISER: As suggested by Mr. Nettleton, the domes in the canyons themselves were initiated by the erosion of the resistant rocks from the canyon, but the Upheaval dome is some distance from any main canyon; it seems to me to be an example of a normal salt dome in an initial stage of deformation.

D. C. BARTON: Where overhang develops, as shown on a considerable number of your domes, what is the condition that initiates that overhang well up toward the top of the dome? There seems to be something that localizes it near the top.

L. L. NETTLETON: The apparent overhang near the top is not analogous to the overhang in nature because it is caused by the constraint imposed by the top of the box.

D. C. BARTON: Is it actually mushroomed against the top?

L. L. NETTLETON: Yes, the oil does finally mushroom against the top.

However, in many cases an overhang develops which is not caused by the top and may form in domes only part way up in the box. If the box is left to flow for a long time, many complicated forms will develop, and the smaller ones, especially, will show a mushroom, or more nearly an inverted tear drop form. However, they do not break away completely, but have a connecting stem to the bottom until the supply of material from below is practically exhausted.

I. I. GARDESCU: In tracing a sand zone away from the salt outward and downward, one finds a thinning of the sand next to the salt, then a gradual development of the sand, both in thickness and size of grains, and further, a thinning of the individual sand streaks and with it, a decided decrease in size of grains. The complete sandy zone, with many shaly breaks, may or may not be thinner than the fully developed sand zone mentioned above. This behavior is significant in relationship to production, correlation, and repressuring operations. Such sand beds are known in some gulf dome structures as well as in the Roumanian salt structures.

The sand accumulation might be due to original deposition or subsequent tectonics. The sand in the area of maximum development shows good sorting and a continuous section with very few, if any, shaly breaks. Should the accumulation be depositional and related to the sinking area surrounding the dome, I fail to understand the narrow development and high permeability of the sand accumulation. The hypothesis of tectonic origin seems to fit the picture better, with the sands being squeezed out from the area immediately surrounding the salt, and the intermediate clay breaks being forced still farther out. What is Dr. Nettleton's opinion on the subject?

L. L. NETTLETON: I do not believe that squeezing resulting from the movement of the salt would materially change the thickness of a sand body. On the other hand, erosion or deposition or both during the time of rise of the dome might be expected to produce such results. Thus, a given stratum might be thinner than normal next to the dome because of erosion during the time of uplift or it might be thicker than normal at some distance out from the dome because it was deposited in a basin formed by a rim syncline. Several instances of this kind are suggested in the diagrams of the hypothetical history of salt domes by fluid flow (Fig. 9).

D. C. BARTON: It would seem theoretically that there should be a variation in the velocity of the growth of the dome through an experiment, and that also in nature at the start of the formation of a dome the differential pressure should be slight; that as the dome grows and the salt rises relatively to the mother salt bed, the differential pressure should be greater and the dome should be able to grow faster. Do you observe that difference in growth?

L. L. NETTLETON: Figure 7 shows just what you mean. The individual pictures were taken at constant time intervals so the change from one picture to another is a measure of the speed of rise. Careful measurements on the original photographs from which this illustration was made show that the speed of rise is directly proportional to the height of the dome until its top is well above the middle of the box. The speed then decreases. A series of direct measurements with a cathetometer has since been made on domes rising within the box. These all show a rate of rise proportional to the height until the top of the dome is about three-fourths of the way to the top of the box. There the speed becomes constant and then rapidly decreases as the dome ap-

proaches the top of the box. The measurements made to date are not sufficient to show whether the decrease of the rate of rise of the dome is caused entirely by the influence of the top of the box or whether it is partly due to the fact that the rising oil moves in a longer and more slender column as the dome rises.

By analogy, we would expect domes in nature to rise very slowly in their early stages. However, the story of their early development is in the rocks which are much below those reached by the drill and we have no way, at present, of knowing the chronology of these early stages.

E. H. SELLARDS, Austin, Texas (written discussion received, April 3, 1934): The theory as to the origin of salt domes, proposed by Mr. Nettleton, suggests the following comments. If the salt mass moves in all respects as a viscous liquid, would there not be a nearly complete mixing of the materials of the salt mass? On the contrary, the stratification in the mass is no more than partially destroyed. This is evident from the presence of a sandstone stratum seen in one of the salt mines in Louisiana, and of anhydrite strata in the salt mine of Grand Saline, Texas. In the German mines the stratification is often sufficiently well preserved to permit determining the principal structural features of the dome. That the salt moves is obvious, but it would seem that it moves as a mass and not as a liquid. Movement in mass results in distortion, but not necessarily total destruction, of stratification.

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REVIEWS AND NEW PUBLICATIONS

Physics of the Earth—VI. Seismology. By the Subsidiary Committee on Seismology, Division of Physical Sciences, with the coöperation of the Division of Geology and Geography, and the American Geophysical Union. *Natl. Research Council Bull. 90* (Washington, D.C., October, 1933). 223 pp., 28 figs. Approx. 7 × 10 inches. Price: paper, $2.00; cloth, $2.50.

This is one of several volumes of the National Research Council dealing with the physics of the Earth. It has for its contributors such well known seismologists as J. B. Macelwane, H. W. Wood, H. F. Reid, J. A. Anderson, and P. Byerly. Each chapter is followed by an excellent bibliography on the subject matter of the chapter.

The first few chapters define and describe tectonic, volcanic, plutonic, and impact earthquakes. Attention is called to the fact that in all probability the great earthquake in Hawaii in 1868 was tectonic in origin, although associated with the eruptions of Kilauea and Mauna Loa.

A discussion of intensity measurements and the various types of scales used also goes into the inherent difficulties in obtaining dependable intensity observations and the need of a far greater number of them. A very interesting discussion is given of the connection between apparent intensity and surface geology. Intensities are compared on the San Francisco peninsula for the 1906 earthquake and conclusive evidence shows that the apparent intensity was substantially less for those areas where bed rock was at the surface or where it was covered by only a few feet of top soil. Made land and areas of thick alluvium received considerably greater shocks.

The theoretical and mathematical aspects of earthquakes are covered by chapters on the elastic rebound theory of tectonic earthquakes and by a mathematical treatment of reflected, refracted and surface elastic waves.

There is a good chapter on the principles of the seismograph showing the difference in requirements for a study of far and near quakes. The problem of deriving the true earth motion from the seismograph motion is taken up and the various equations of the seismograph are considered in this connection.

Some space is devoted to the study of seismograms and the various P and S waves. A discussion of methods for finding the epicenter and focal depth, and for deriving time-distance curves is included.

Maps show the areas of greatest seismic activity. In general such areas have one or more of the following characteristics: (1) Tertiary mountain systems; (2) regions where height has increased during and since Tertiary time; (3) substantial surface gradients; (4) coastal regions; (5) volcanic regions.

<div align="right">B. B. WEATHERBY</div>

TULSA, OKLAHOMA
July, 1934

Tertiary Faunas. A text-book for oil-field paleontologists and students of geology. Vol. II, *The Sequence of Tertiary Faunas*. By A. MORLEY DAVIES. 252 pp., 28 figs., frontispiece. Outside dimensions, 8.75×5.75 inches. Demy 8vo. Cloth. Thomas Murby and Company, 1 Fleet Lane, London, E.C. 4 (1934). Price, net, 15s.

This very readable and instructive book by Dr. Davies includes a mass of facts presented in a most interesting fashion, making a very valuable history of the Tertiary fauna. The book consists of four chapters, each chapter appended by a complete bibliography. The index, including seventeen pages, is most valuable as it lists all the genera mentioned in the text as well as authors and subjects.

The first chapter, dealing with the geographical distribution of animal life, first clearly defines the following terms: *communities*, *faunas*, *stations*, and *provinces*. Two types of species are defined.

The term *euryopic* is used to denote forms which range through a variety of stations (whether determined by depth or by other conditions) in contrast to *stenopic* forms which are confined to one particular type of station, [a station being a local area with its] community consisting of many species of animals and plants related to one another as enemies and prey, as competitors for the same food, or as more or less unconscious coöperators.

Areas separated by barriers are *provinces* or *regions* and include many stations with their *communities*. Usually a province is characterized by a distinct fauna although not completely confined to that particular province. After a thorough discussion of the manner of distribution of the fauna and the barriers to dispersal, the author gives descriptions of the various provinces with the characteristic existing animal life.

In his second chapter, which deals with the geological interpretation of fossils, the author states that

the practical value of fossils lies in the use that can be made of them in geological mapping and correlation. They may be used to date a deposit with a variable degree of precision; to prove the identity of a bed the outcrop of which cannot be traced continuously; to correlate the beds in a boring with surface outcrops; to discriminate between two beds of similar lithology. If, however, fossils are used by rule of thumb alone, there are traps and pitfalls that cannot be avoided. Some understanding of the conditions which control the life and evolution of organisms is essential to the intelligent judgment of the evidence that fossils offer.

Then follows a discussion of facies fossils and zone fossils. A diagrammatic section across the Lutetian beds of the Paris basin shows the relationship and variation in paleontological and lithological facies. Faunal facies variations are dependent on cycles of sedimentation, which are to be taken into consideration when determining zone-fossils. Lyell's classification by means of the percentage of Recent species of *Mollusca* in their faunas is given.

The third chapter gives a very long and detailed discussion of the early Tertiary faunas, including land faunas as well as marine, vertebrates as well as invertebrates. The early Tertiary or Paleogene includes the Paleocene, Lower Eocene, Middle Eocene, Upper Eocene, and Oligocene epochs. A complete history of the geographical and faunal changes of each epoch is given. The succession of the epochs and the faunas of each epoch are described from

the various parts of the world. The late Cretaceous faunas, which included the ancestors of the early Tertiary forms, were distributed into two large provinces: the Boreal extending across northern Europe, from Britian to Russia, from New Jersey to Texas; and the Tethys extending from Colombia, Mexico, and Jamaica, in the west, through the lands bordering the Mediterranean, Syria, and Persia, to Tibet, northwestern India, and possibly the East Indies. The author states that the Midway fauna from Alabama to Texas is Paleocene and shows nearer relationship to the Old World Boreal than to the Tethyan fauna. The Aragon formation of Mexico contains some Midway species. On the Pacific Coast of North America the Martinez formation has many species in common with the Midway. But there is no satisfactory evidence of Paleocene faunas on the Pacific Coast of South America. The author brings out the fact that the Lower Eocene strata are more generally marine than the Paleocene and in many areas overlap the Paleocene onto the Cretaceous. Likewise, Lower Eocene is in turn overlapped by Middle Eocene, during which time the marine trangression reached its greatest extent. The best known Lutetian (Middle Eocene) is that of the Paris basin. The Claiborne of Alabama has many species in common with the Paris basin fauna although many species of the latter are absent.

The fourth chapter deals with the Neogene or later Tertiary faunas of Miocene and Pliocene age.

The marine molluscan faunas of the Miocene epoch are distinguished from those that precede them, at least in the more familiar regions of the world, by two features: (1) the sudden appearance in great numbers of certain families of gastropods previously represented by a few isolated genera or species, (2) the appearance of numerous species still living in our seas. It is doubtful if any Recent species range back to the Eocene, while those in the Oligocene are too few to count as a definite percentage.

The Mediterranean fauna is treated at length, followed by an analysis of both marine and terrestrial faunas by provinces all over the world. A great deal of attention is given to the mammalian fauna of the Miocene and Pliocene.

A summary of all the foregoing correlations is given in two correlation charts in the appendix. The Lower Tertiary marine formations from all over the world are correlated in Table I, those of the Upper Tertiary marine formations in Table II. The mammalian faunas of Older Tertiaries (Table III) and of Newer Tertiaries (Table IV) are listed from Africa, Asia, North America, and South America.

This book was written to serve as a text-book for petroleum paleontologists. The subject of micropaleontology, which in all parts of the world is becoming the most useful of all paleontological work for oil geologists, is not treated. Larger *Foraminifera* are referred to in several places. In a text-book intended for oil-field paleontologists a discussion of the smaller *Foraminifera* should be included. A treatise on Tertiary faunas is not complete without them.

<div align="right">ALVA C. ELLISOR</div>

HOUSTON, TEXAS
June 27, 1934

Catalogue of Small Scale Geological Maps (Preliminary Edition), 1933. By WALTER H. BUCHER and a staff of contributors. 132 mimeogr. pp.; size 8.5×10.5 inches. National Research Council, 2104 Constitution Avenue, Washington, D.C. Price, $1.00.

The preface states,

The titles of geological maps contained in this catalogue were collected to form a working basis for broader regional studies. They were intended primarily as a foundation for synthetic work on world-tectonics. But they will be found useful by all who are concerned with regional studies extending beyond their own country in physical geography, in paleogeography, and in economic geology. The specific purpose of this catalogue limits it to maps representing larger areas, in contrast to the multitude of maps that show the details of the geology of a relatively small number of square miles.

The area catalogued in Part I is the North American continent and the West Indies. Each map is indexed as to geographic location, title, author, date, scale, and where published.

This appears to be a very useful and worth while publication and should be a valuable addition to the files of any geologist interested in regional geology.

A. I. LEVORSEN

HOUSTON, TEXAS
July 12, 1934

"A Study of Barnegat Inlet." By JOHN B. LUCKE. *Shore and Beach* (Journal of the American Shore and Beach Preservation Association, New Orleans, Louisiana), Vol. 2, No. 2 (April, 1934), pp. 1–94.

The fact that many oil pools in the Mid-Continent region occur in long, narrow sand bodies which have been interpreted as buried offshore bars with their associated tidal inlets and tidal deltas, makes Lucke's detailed study of a typical offshore bar, tidal inlet, and tidal delta of special interest to geologists who have to do with fossil sand-bar oil pools.

The paper includes a history of the evolution of Barnegat inlet from the time of the earliest charts to the present; a discussion of tidal conditions— the differences in the height of the tides in the lagoon and in the open ocean, the times of high and low water at different places, and the phenomena associated with the inflow and outflow of the tidal currents through the inlet; a sedimentation study of the composition of the tidal delta based on numerous bottom samples and a series of selected cores extending to depths as great as 30 feet; a "theory of evolution of lagoon deposits on shorelines of emergence"; and a description of the field methods and apparatus used in the bottom sampling, coring, and measurement of current velocities. The paper is illustrated by charts, sketches, and several excellent aerial photographs and mosaics.

The investigation revealed that the tidal range within the lagoon is noticeably less than on the ocean side of the bar and that the velocity of the outgoing tidal current through the inlet is considerably greater than that of the incoming current. For the past hundred years or more the inlet has been shifting southward. Criteria are developed by means of which the author thinks it may be possible to read the history of the migrations of an inlet through a study of the form of the tidal delta and of the sediments of which it is composed.

The tidal delta opposite Barnegat inlet is composed almost exclusively of sand which has been drifted by longshore currents along the outer side of the offshore bar, carried through the inlet by tidal currents, and deposited in the general form of a delta in the lagoon. As might be expected, the sand becomes finer with distance from the inlet. No stratification could be recognized in the cores of the tidal delta sediments, presumably because of the great uniformity of the material. Organic material is abundant in the upper 2 or 3 feet of the delta sediments, but is almost entirely absent below. This scarcity of organic material below the upper few feet of the sediments is believed to be due to its removal by bacterial or other agencies, for the conditions of deposition are not believed to have changed recently, because an abundant and uniform micro-fauna is found throughout the depth of sediments cored. In three restricted areas, black organic material is so strongly concentrated that it forms a jet-black, highly gelatinous ooze.

Lucke's theory of evolution of lagoon deposits seems to the reviewer to fit the special rather than the general case, because it assigns an important rôle to headlands to which the bars are directly or indirectly tied, and from which most of the sediment which builds the bars and, indirectly, the tidal deltas, is carried by longshore currents. Along bar-bordered coasts, such as those of North Carolina and Texas, the bars are strictly offshore and headlands are absent or relatively small in extent. The same was probably true of the coasts along which the sand-bar oil pools of the Mid-Continent region were formed. A general theory of evolution of lagoon deposits should include coasts without important headlands.

JOHN L. RICH

OTTAWA, KANSAS
July 25, 1934

Earth, Radio, and the Stars. By HARLAN TRUE STETSON. McGraw-Hill Book Company, New York (1934). xvii + 336 pp., 88 figs. Price, $3.00.

A beautiful frontispiece showing a cross section of the earth's crust and atmosphere serves as a graphic portrayal of the phenomena discussed in the book.

In the "Preface" it is stated that the volume is written for the purpose of bringing together recent developments in astronomy and its related fields of physics, chemistry, geology, meteorology, and even biology, which may suggest a more intimate relationship between man and his cosmic environment. In a certain sense, the volume is a continuation of an earlier volume, "Man and the Stars," in which is sketched the development of astronomy from pre-Copernican days to the present time.

Under the title, "The Approach," the main facts concerning the earth and its cosmic environment are passed in review. In anticipation of the future, it appears that the era of dynamical astronomy is to be replaced by the equally difficult field of celestial electronics.

Chapter I, "The Twin Planet," contains a general description of the motion of the solar family through celestial space. The rather complicated motions of the earth-moon system resulting in the change of seasons and the precessional motion of the earth's axis are explained in considerable detail.

Variation of latitude is discussed in Chapter II, under the title, "The Wandering Poles." Theory proves conclusively that the instantaneous axis

of rotation of a symmetrical body like the earth generates a cone about the axis of figure when the two axes do not coincide. The instantaneous pole of rotation describes a circle about the pole of figure. For a rigid earth the time required for the instantaneous pole to describe the complete circle is 305 days. Chandler found, instead, a period of 428 days. This difference between theory and observation is due to the mobility of the water in the oceans and a small amount of elasticity possessed by the earth.

The problem of the progressive shift of land masses is involved in the problem of latitude variation. Because of the great importance of this subject, an International Latitude Survey was inaugurated in 1900. The importance of international coöperation on such projects can not be overestimated.

Is the earth sufficiently elastic to yield to the gravitational pull of the moon? A preliminary answer to this question is given in Chapter III, "Does the Moon Change the Latitude?" The answer to this question is found in several figures which show clearly the variation of latitude with the hour angle of the moon. A north and south displacement of ten feet in the observing station produces a change of 0".1 in the observed latitude. The extreme range of variation is about 0".40 with an interval between peaks of about 428 days.

As a further means of analyzing the land movements that may occur every day under the attraction of the moon, a rather complete though elementary analysis of "Ocean Tides" is given in Chapter IV. This chapter provides the theoretical basis for Chapter V, "Earth Tides."

That earth tides exist is evidenced by the fact that the height of ocean tides is much less than is indicated by theory. The question of how much the solid earth may yield to the tide-raising forces was the subject of a notable investigation in 1913–15 by Michelson and Gale on the grounds of the Yerkes Observatory at the University of Chicago. The experiment consisted in measuring the changes in level of water in horizontal pipes 500 feet long, one in a north and south, the other in an east and west direction. Analyses of the observations showed that the solar and lunar waves were only about 70 per cent of what they should have been had the earth been rigid. This result justifies the assumption of elastic displacements in the crust of the earth. But the story does not end here. If there are elastic displacements in a north and south direction, why not in an east and west direction, as well? This question brings us to Chapter VI, "Variation in Longitude."

The astronomical evidence consists of two sets of data. It was found first that the clock errors at Washington and Ottawa, Canada, varied with the hour angle of the moon. In the second place, it was found that the difference in time between Washington and Greenwich as determined by radio signals depends upon the latitude of the moon. A change in distance between the two cities of about 63 feet, or a variation of 32 feet either way from the average positions, suffices to explain the observed variations in longitude. This displacement is equivalent to an elongation of only one part in 100,000, an amount well within the elastic limit of granitic rocks. The average transmission time across the Atlantic is 0ˢ.04.

Chapter VII, "The Earth from the Inside," gives an interesting review of various hypotheses of the origin of the earth. From a study of seismic waves, it is inferred that the central core has a radius of 3,470 kilometers (2,150 miles); then there is a transition layer of silicates impregnated with iron of a

thickness of 1,700 kilometers (1,056 miles); next, is a layer of silicon-magnesium (sima) with a thickness of 1,140 kilometers (700 miles): resting on this layer are the ultra-basic (sial) or granitic rocks with a thickness of 23 kilometers (14 miles). The basaltic layer is a direct support for the surface crust, composed chiefly of granite rocks with a thickness of some 12 kilometers (7.5 miles). The basaltic rocks are believed to be more or less plastic. They form a weak substratum for supporting the overlying crust. Yielding of the basaltic layer under the weight of the granitic crust frequently results in earthquakes.

The Taylor and Wegener hypothesis of continental migrations is discussed in considerable detail. Joly's hypothesis of radioactive melting of the sima is seen to result in a possible tidal effect that would move the sial westward. Extensive studies by Cotton indicate that earth tides may be the means of initiating earthquakes in strata that are strained almost to the breaking point.

The sun is a million times larger than the earth and a million times smaller than many of the stars. Chapter VIII deals with the problem of "The Sun's Effects on Human Affairs." Fluctuation in the solar radiation may be a major factor in the problem of long-range weather forecasting. The solar cycle of eleven years has been registered in the rings of trees. It is suggested that it may be related to the life cycle of infectious micro-organisms as well as to the recurring cycles of the economic world.

Graphs in Chapter IX, "Sun-Spots and the Earth's Magnetism," show clearly the dependence of the earth's magnetic activity on sun-spot numbers. One source of the earth's magnetism is the nickel-iron core that retains a more or less permanent magnetic set, like that of a steel magnet. The chief remaining source appears to be streams of ions, electrons, and possibly neutrons and positrons which come into the earth's atmosphere after being ejected from the sun spots.

Chapters X to XVI, inclusive, deal almost entirely with the results obtained by means of that marvelous new instrument of research, the radio. The titles of these interesting articles are: "Sun-Spots and Radio Reception," "The Sun and the Ionized Layer," "Transatlantic Radio Transmission," "The Moon and Radio," "Solar Eclipses and Radio," "Meteors and Radio," and "Radio and the Stars."

The Aurora Borealis, the Zodiacal Light, and the Gegenschein are discussed under the general topic, "Illuminations of the Night Sky."

The possible presence of cosmic material of very low density is discussed under the title, "Cosmic Clouds."

The most fascinating scientific subject of the day is "Cosmic Rays." So penetrating are these rays that an electroscope enclosed within lead walls having a thickness of 5 or 6 feet would be discharged in a comparatively short time.

By analogy with the word "Ecology," that branch of biology which treats of the relations between organisms and their environment, it is proposed to use the word "Cosmecology" as the name for that science which treats of the earth in its relation to the cosmos. The development of such a science concerns the geologist, the physicist, the meteorologist, the radio engineer, the astronomer; and even the biologist and the economist may be needed to obtain complete answers to nature's numerous problems. Science has just passed

through a highly analytic age—the science of the future must mold these highly specialized fields into a unified science of the whole.

As indicated in the preceding sketch, the book contains a fund of rather detailed information for the research worker. For the popular reader, it is a very interesting exposition of the marvels of science in a number of different fields.

The book concludes with a good bibliography. There is also an author and subject index.

C. E. VAN ORSTRAND

UNITED STATES GEOLOGICAL SURVEY
WASHINGTON, D.C.
July 26, 1934

The Geology of British Somaliland. By W. A. MACFADYEN. Part I of the Geology and Palaeontology of British Somaliland. Published by the Government of the Somaliland Protectorate (June, 1933). 87 pp., 4 pls., geol. map. Copies obtainable from the Crown Agents for the Colonies, 4, Millbank, London, S.W. 1. Price: 12s. 6d., net.

We again have the oil companies to thank for an extension of our knowledge of regional geology, as this volume represents largely the results of work done for the Somaliland Petroleum Company. W. A. Macfadyen, the present government geologist, directed the company's explorations carried on from 1928 to 1930. During this period an area of more than 100,000 square kilometers (out of a total area of 177,000 square kilometers) was mapped geologically for the first time. Combining this new information with the previous work of C. Barrington Brown and R. A. Farquharson, government geologists, and of the Anglo-Persian Oil Company under B. K. N. Wyllie and W. R. Smellie, the author has given us a comprehensive idea of the geology of the entire country. The geologic map (scale 1:1,000,000) covers all but a few small areas.

The topography of the country reflects the structure, and this is controlled almost entirely by block faulting. The few folds observed are minor in scale and obviously resultant from the faulting. The main fault occurs along a very old line of weakness, but now represents movement from Tertiary time to the present. Its great scarp, with a maximum throw of about 2,400 meters, extends from east to west across the country, facing the Gulf of Aden (the downthrown segment) to the north and separated from it by 30–80 kilometers of coastal plain and hill country. From this scarp the main part of the country slopes gently to the south. The drainage is toward the north and south, divided by the scarp, and shows evidence of being superimposed. The streams are intermittent and predominantly subsurface.

While the final study of the fossil collections may entail minor revisions, the main stratigraphic sequence has been pretty thoroughly established. Unmetamorphosed sedimentary beds, ranging from Triassic to Recent, overlie an Archean basement complex of igneous and metamorphic rocks. The only other igneous rocks are Pliocene to Recent extrusives. One of the most striking problems presented here is the exposure of a great anhydrite formation, covering about a fifth of the region, without any evidence of the usual accompanying salt and gypsum.

There is a comprehensive bibliography. Numerous stratigraphic sections are given in detail. The important question of water supply is discussed in an

appendix. Others give a report on the igneous rocks by A. Harker and a list
of localities for fossils on which we are promised a report at a later date.

MARGARET C. COBB

NEW YORK, N.Y.
July, 1934

National Oil Scouts Association Year Book, 1934. 148 pp., 7 maps. Size, 8×10.5
inches. Send check for $5.00 to C. O. Falk, Box 1084, San Antonio, Texas.

The Oil Scouts' Year Book for 1934, compiled by active members of the
National Oil Scouts Association of America, covers the oil and gas develop-
ment for the year 1933 and brings together information on the various dis-
tricts of Texas, Louisiana, southeastern New Mexico, south Arkansas, Mis-
sissippi, and western Alabama.

The production schedules of the various fields show the total number of
barrels of oil produced during 1933, total number of barrels to date, total
wells drilled, total wells producing, estimated number of productive acres,
depth, and formation producing. Maps cover the producing fields, known salt
domes, and prospective salt domes in the Texas and Louisiana Gulf Coast
region, and oil and gas fields of southwest Texas.

Other information of interest is a detailed salt-water report covering the
East Texas field, which lists the operators, leases, well numbers, surveys, per-
centages of basic sediment and water, and the total barrels of salt water pro-
duced daily. Tables are given showing the wildcat lease situation by counties,
in the various districts, and a summary of wildcat drilling operations during
the year 1933.

Articles of unusual interest in the Year Book are: "A Résumé of General
Activity in the Fault Zone and Edwards Plateau Areas, Southwest Texas
District"; "General Comments on Developments in 1933, North Louisiana
and South Arkansas District"; "Field Technique of the Magnetometer and
Its Use in Locating Serpentine Plugs"; and "The Advent of the Chemical
Industry into the Southwest Texas Area."

JESSE L. BULLARD

SAN ANTONIO, TEXAS
June, 1934

Geologic History at a Glance. Compiled by L. W. Richards and G. L. Richards,
Jr. Stanford University Press, Stanford University, California (1934).
Price of educational edition, $0.80; bound, $1.25.

This compact and concise publication gives a visual idea of the succession
of rocks on the earth as interpreted by geologists. The main part consists of
two large plates bound in heavy paper (size, 8.5 by 11 inches) and punched
to fit a classroom notebook. On these plates has been drawn the geologic time
scale which is connected with photographs showing the strata of the same age.
This arrangement is particularly enlightening to most non-geologists who
have difficulty in visualizing the manner in which strata occur and linking
their natural appearance with the ordinary text-book drawings or explana-
tions. The pictures are all well chosen to show the succession of strata.

Plate 1 gives the standard geologic column which is diagrammatically
tied in with photographs of the Tertiary of San Joaquin Valley, the Mesozoic
of the Moab district, Utah, and Paleozoic of the Grand Canyon.

Plate 2, entitled "The Rock Column Building, or the Geologic Hall of Time and Records," is similar in many ways to Plate 1, but gives another illustration of the succession of strata with the relative length of time involved in their deposition. For the Tertiary section an aerial view of a part of the west side of San Joaquin Valley (Kreyenhagen and Kettleman Hills) is used. This Tertiary section is tied in graphically with that at Bryce Canyon-Zion Canyon, and from that into the Grand Canyon.

The inside cover is devoted to a brief summary of the geologic column, which also is an explanation of the two plates. However, no reference is made as to why the complete geologic section can not be illustrated from a single locality or area. The reason for tying in the Colorado Plateau section with the San Joaquin Valley may not be clear to beginners in geology.

The back cover contains a selected bibliography of literature.

In a subsequent edition a few mistakes should be corrected. Sponges are not single-celled organisms, nor are corals classed as plants. Also, in the graphical sketch of the percentages of time for the eras during earth history, the figures total 99.1 per cent. What has become of the other 0.9 per cent of time to date? The authors take exception to most time classifications, including that of the United States Geological Survey, and do not include the Recent period within the Cenozoic era.

In Chart 1 the formations included in the Pleistocene epoch are the San Pedro, Timm's Point, and Las Posas. These are classed as terraces, gravels, glacial deposits, whereas all are of marine origin. The last two names, furthermore, are not well selected to represent the Pleistocene of California.

Compiled by California men, it is apparently designed for use in the western part of the United States. It is written in language too technical for the average layman, which will detract from a more general use. However, for high school or university students it should serve as a valuable aid in the early stages of their geology course.

WILLIAM S. W. KEW

Los ANGELES, CALIFORNIA
August 9, 1934

RECENT PUBLICATIONS

CANADA

"Palaeozoic and Jurassic Formations in Well Sections in Manitoba," by R. T. D. Wickenden. *Geol. Survey of Canada Summ. Rept. 1933*, Part B (Ottawa, 1934), pp. 158–68.

"Deep Borings in the Prairie Provinces," by W. A. Johnston. *Ibid.*, pp. 169–70.

"Borings in Eastern Canada," by W. A. Johnston. *Ibid.*, Part D, pp. 155–56.

COLOMBIA

Compilacion de los estudios geologicos oficiales en Colombia—1917 a 1933 (Compilation of Official Geological Work in Colombia from 1917 to 1933). Vol. I (1934). Prepared for the National Scientific Commission under the direction of Roberto Scheibe. Ministerio de Industrias, Biblioteca del Dept.

da Minas y Petroleo, Bogota, Colombia. 475 pp., 79 figs., 9 pls. in color. Outside dimensions, 6.625×9.625 inches.

GENERAL

Geologic Structures, by Bailey Willis and Robin Willis. 3d. ed., revised. McGraw-Hill Book Company, New York (1934), 544 pp., 202 figs. 5.25×7.5 inches. Flexible cover. Price, $4.00.

"Upper Mississippi Valley Structure," by A. C. Trowbridge. *Bull. Geol. Soc. Amer.*, Vol. 45, No. 3 (Washington, D.C., June 30, 1934), pp. 519–28; 1 fig.

Geologic History at a Glance, compiled by L. W. Richards and G. L. Richards, Jr. Stanford University Press, Stanford University, California (1934). Two folded diagrammatic-photographic charts of the geologic column, with brief explanatory text and references on inside front and back covers. Size, folded within covers, 9×11.25 inches. Price: educational edition, $0.80; trade edition, $1.25.

Gorman's Petroleum Directory of Oklahoma, 1934. Compiled by B. R. Gorman. List of companies and individuals in Oklahoma directly or indirectly connected with the production of petroleum. 86 pp. 4.5×7.5 inches. A new revised issue will be published in 1935. Orders should be sent to Box 395, Tulsa, Oklahoma. Price, $1.00.

GEOPHYSICS

Angewandte Geophysik für Bergleute und Geologen (Applied Geophysics for Engineers and Geologists), by Hermann Reich. Part II: 153 pp., 73 figs. *Akad. Verlags. M. b. H.*, Leipzig (1934). Paper. Price, M. 10.60.

PENNSYLVANIA

"Possibilities of Finding Gas in the Oriskany Sand in McKean County," by S. H. Cathcart. *Pennsylvania Topog. and Geol. Survey Bull.* 111 (Harrisburg, May, 1934). 13 pp., 3 figs.

"The Possible Occurrence of Gas in the Oriskany Sand of Elk County," by S. H. Cathcart. *Pennsylvania Topog. and Geol. Survey Bull.* 110 (April, 1934). 21 pp., 3 figs.

TURKEY

"Übersicht der Erdölvorkommen in der Türkei" (Review of Petroleum Occurrences in Turkey), by Gregor Petunnikov. *Petrol. Zeit.* (Berlin), Vol. 30, No. 27 (July 4, 1934), pp. 17–21; 6 figs.

PERIODICAL LIBRARY SERVICE

A complete list of technical periodicals currently received at Association headquarters is here printed. Members and associates in good standing may borrow from this library by giving satisfactory assurance that loans will be returned promptly, by assuming responsibility for cost of replacement if lost or damaged, and by paying all transportation charges. Loans will be sent to the borrower, with transportation charges collect; they are to be returned with transportation prepaid, within 5 days after receipt by borrower. Requests for loans may be deferred or refused if periodicals are needed for edi-

torial purposes; or in case of periodicals for which there are frequent requests and transportation to and from the applicant requires a total of more than 10 days. Photostat copies will be supplied at regular charge of $0.30 per page plus any incidental expense. Write to Association headquarters, Box 1852, Tulsa, Oklahoma.

TECHNICAL PERIODICALS

UNITED STATES

Professional

1. American Journal of Science, New Haven, monthly
2. Bulletin of the Geological Society of America. Washington, bi-monthly
3. California Journal of Mines and Geology. San Francisco, quarterly
4. California Oil Fields. San Francisco, quarterly
5. Economic Geology. Urbana, semi-quarterly
6. Journal of Geology. Chicago, semi-quarterly
7. Journal of Paleontology. Fort Worth, quarterly
8. Journal of Sedimentary Petrology. Fort Worth, 3 per year
9. Louisiana Conservation Review. New Orleans, monthly
10. Mining and Metallurgy. New York, monthly
11. Pan-American Geologist. Des Moines, monthly
12. Proceedings of the U.S. National Museum. Washington, occasionally
13. Science. New York, weekly
14. U.S. Bureau of Mines publications. Washington, occasionally
15. U.S. Geological Survey publications. Washington, occasionally

Trade

16. American Petroleum Institute Quarterly. New York
17. California Oil World. Los Angeles, weekly
18. Independent Monthly. Tulsa
19. Inland Oil Index. Casper, weekly
20. National Petroleum News. Cleveland, weekly
21. Oil and Gas Journal. Tulsa, weekly
22. Oil Weekly. Houston
23. Petroleum Engineer. Dallas, monthly
24. Petroleum World. Los Angeles, monthly
25. World Petroleum. New York, monthly

AUSTRIA

26. Internationale Zeitschrift für Bohrtechnik, Erdölbergbau und Geologie (International Journal of Drilling Technique, Petroleum Mining, and Geology). Vienna, monthly

BELGIUM

27. Revue de Géologie (Review of Geology, abstracts in language of author). Liège, monthly

ENGLAND

28. British Museum of Natural History publications. London, occasionally
29. Journal of the Institution of Petroleum Technologists. London, monthly
30. Proceedings of the Geologists' Association. London, quarterly
31. Quarterly Journal of the Geological Society of London

FRANCE

32. Annales des combustibles liquides (**Annals** of Liquid Fuels). Paris, bi-monthly
33. Bulletin de la société geologique de France (Bulletin of the Geological Society of France). Paris, 9 per year

34. Chronique des Mines Coloniales (Mining Chronicle of the French Colonies). Paris, monthly
35. Revue pétrolifère (Petroleum Review). Paris, weekly

GERMANY

36. Abhandlungen Senckenbergischen naturforschenden Gesellschaft (Proceedings Senckenberg Naturalists Society); also Senckenbergiana. Frankfurt, bi-monthly
37. Archiv für Lagerstätten-Forschungen und Abhandlungen der Preussischen geologischen Landesanstalt (Prussian Geological Survey publications). Berlin, occasionally
38. Geologische Rundschau (Geological Review). Berlin, bi-monthly
39. Geologisches Zentralblatt (Geological Abstract Journal). Leipzig, semi-monthly
40. Kali, verwandte Salze und Erdöl (Potash, Related Salts and Petroleum). Berlin, semi-monthly
41. Mineralogisch-Geologisches Staats-Institut (Mineralogy-geology publications of the State Institute). Hamburg, occasionally
42. Petroleum Zeitschrift (Petroleum Journal). Berlin, semi-monthly
43. Zeitschrift für praktische Geologie (Journal of Applied Geology). Halle, monthly

HOLLAND

44. Leidsche Geologische Mededeelingen (Leyden Geological Journal, in Dutch, German, and English). Leyden, occasionally

HUNGARY

45. Földtani Szemle (Hungarian Review of Geology and Paleontology). Budapest, occasionally

INDIA

46. Records of the Geological Survey of India. Delhi, occasionally

ITALY

47. Scientia (Science, language of author). Milan, monthly

JAPAN

48. Journal of the Faculty of Science of Hokkaido University (in English). Sapporo, occasionally

PERU

49. Boletin de la Sociedad Geologica del Peru (Bulletin of the Geological Society of Peru). Lima, occasionally

POLAND

50. Geologja i Statystyka Naftowa Polski (Geology and Statistics of Petroleum in Poland, in Polish). Borysław, monthly
51. Sprawozdania Polskiego Instytutu Geologicznego (Bulletin of the Geological Survey of Poland, in Polish). Warsaw, occasionally

RUSSIA

52. Bulletin of the United Geological and Prospecting Service, U.S.S.R. (in Russian). Leningrad, occasionally
53. Neftianoje Chosiaystwo (Petroleum Industry, in Russian). Moscow, monthly
54. Problems of Soviet Geology (in Russian with summaries in English). Moscow, monthly

UGANDA

55. Annual Report of the Geological Survey Department, Uganda Protectorate. Entebbe, occasionally

NATURAL GAS IN POLAND

CORRECTION

In the article, "Natural Gas in Poland," by K. Tolwinski, in the *Bulletin*, Vol. 18, No. 7 (July, 1934), the following corrections should be made.

P. 896, Fig. 4 cut line should read, "Map showing gas fields of Potok and *anticlinal* folds of Eocene sandstone."

P. 897, line 5 should read, "The oil and gas occur *in sandstones* in joints and in free spaces between the beds."

P. 897, line 3 from bottom, change "synclinal" to *anticlinal*.

THE ASSOCIATION ROUND TABLE

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*Honorary.. 1

Total additions since publication of list in March *Bulletin*....64

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Memorial

D. BRUCE SEYMOUR

D. Bruce Seymour died in a hospital in San Bernardino, California, May 27, 1934, soon after incurring third-degree burns from an accidental fall into a camp-fire. Coming from the darkness into the fire light with an armload of wood, he tripped over an unseen log, after depositing the wood, and fell into a bed of hot coals which ignited his clothing instantly and the burns causing his death resulted, even though he jumped out of the coals immediately and extinguished the blaze.

Seymour was born April 21, 1902, at Santa Rosa, California. He attended elementary schools in Santa Rosa and from 1920 to 1924, studied at Stanford University, from which he graduated with an A.B. in geology. He is survived by his wife, Consuelo Willard Seymour, a beautiful little daughter Nancy, his three sisters, and two brothers.

Soon after leaving college he entered the employ of Marland Oil Company of California, now Continental Oil Company, and was engaged in geological work with that organization in California until his death. He was elected to full membership in the Association in 1928 and had contributed much to the activities of the Pacific Section. Two of his outstanding works were the geology of Santa Rosa Island off the coast of California and a practical application of the geometric methods of Busk to California geologic conditions.

Bruce was a lover of nature and had become intensely interested in Pacific Coast native flora. His avocation was gardening, where nature readily responded to his magic influence with gorgeous gladioli, dahlias, and chrysanthemums as well as transplanted wild flowers. At the memorial services a beautiful floral tribute surrounded him in death as in life.

Of less than normal stature, Bruce was a mountain of strength, possessed unlimited energy and enthusiasm and was endowed with a most keen intellect and dynamic personality. He was one of California's outstanding geologists and had packed an eventful life and much geologic experience into the ten years since graduating from the university. His untimely death checked a career that would have led to the heights of his chosen profession.

Honest, lovable, human—Bruce leaves hosts of friends who mourn his passing and will hold him in affectionate memory.

R. M. BARNES

LOS ANGELES, CALIFORNIA
June 28, 1934

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

C. W. ECKENWILER has changed his address from 507 Philcade Building, Tulsa, Oklahoma, to 1428 Esperson Building, Houston, Texas.

GLENN D. ROBERTSON, geologist with the Shell Petroleum Corporation, has been transferred from Wink, Texas, to Hobbs, New Mexico.

PAUL A. SCHLOSSER, geologist for Phillips Petroleum Company, has been transferred from San Angelo to Midland, Texas.

CARY P. BUTCHER has been employed by the Tide Water Oil Company as district geologist for the West Texas-New Mexico district with headquarters in the Petroleum Building at Midland, Texas.

HARRY W. McCOBB, formerly with the Tropical Oil Company, Barranca Bermeja, Colombia, S.A., may now be addressed at Nederlandsche Koloniale Petroleum Maatschappij, Soengei Gerong, Palembang, Sumatra, D. E. I.

GEORGE OTIS SMITH has changed his address from 2137 Bancroft Place, Washington, D.C., to Box 308, Skowhegan, Maine.

D. DALE CONDIT has been occupied during recent months in a study of oil possibilities in various parts of Australia, including the states of Queensland, Victoria, and West Australia. He is now engaged in an inspection of various parts of New Guinea, using an amphibian airplane as principal means of transportation.

R. G. RYAN has been employed by the Tide Water Oil Company as geologist to work in southern Louisiana.

HEATH M. ROBINSON, geologist, has moved his office from 815 Tower Petroleum Building, to 406 Continental Building, Dallas, Texas.

WILLIAM S. HOFFMEISTER, paleontologist for the Lago Petroleum Corporation at Maracaibo, Venezuela, has been transferred to the Standard Oil Company of Venezuela, at Caripito, where he will act in the same capacity. He may be addressed at Caripito, Venezuela, via Trinidad, B. W. I.

JAMES L. BALLARD, formerly with The Texas Company, Houston, Texas, is now with the Stanolind Oil and Gas Company, Box 660, Tyler, Texas.

V. C. SCOTT has been made district geologist for The Texas Company, at Oklahoma City, where the company has recently opened a district geological office.

Oklahoma City University conferred on June 1 the honorary degree of doctor of laws upon CHARLES NEWTON GOULD, formerly director of the Oklahoma Geological Survey.

GEORGE F. KAY has resigned from the positions of head of the department of geology of the University of Iowa, and state geologist of Iowa. He will retain his administrative duties of dean of the College of Liberal Arts, member of the staff of the Geological Survey, and professor of geology in the university. A. C. TROWBRIDGE has been appointed to succeed Dr. Kay in the two vacant positions. A. C. TESTER has been appointed assistant state geologist to succeed JAMES H. LEES, who recently resigned on account of ill health.

R. E. GILE has been employed as paleontologist for the Tide Water Oil Company to work in the West Texas district with headquarters at Midland, Texas.

HAROLD VANCE, Kilgore, Texas, has been appointed head of the department of petroleum engineering at the Texas Agricultural and Mechanical College, College Station. The appointment became effective September 1.

VIRGIL B. COLE, geologist with the Gypsy Oil Company, has been transferred from Ada, Oklahoma, to Wichita, Kansas, and may be addressed at the Union National Bank Building.

HARRY X. BAY is now at Cole Camp, Missouri.

JOHN H. WILSON, as president of the Colorado Geophysical Corporation, has opened a suite of offices in the Midland Savings Building, Denver, Colorado. KEATING RANSONE, formerly secretary of the Geophysical Service, Incorporated, Dallas, Texas, has been made office manager for the new Denver offices. Active geophysical prospecting is being carried on in the Rocky Mountain area by the firm.

HOWARD E. ROTHROCK, of the United States Geological Survey, has been transferred from Oklahoma to Washington, D.C.

LOUIE C. KIRBY, geologist with the Louisiana-Arkansas division of The Texas Company, Shreveport, Louisiana, sailed from New York on August 11 to assume duties as geologist and micro-paleontologist with The Texas Exploration Company at Buenos Aires, Argentina.

JERRY E. UPP, who was on leave of absence during the past year from the Nebraska Geological Survey to study the occurrence and distribution of selenium for the United States Department of Agriculture, has accepted the position of micro-paleontologist with the Amerada Petroleum Corporation at Wichita, Kansas.

GEORGE EDWIN DORSEY, chief geologist of Magnolia Petroleum Company, Dallas, Texas, has been permanently transferred to the New York offices of the company. His new address is Geological Department, Socony-Vacuum Oil Company, Incorporated, 26 Broadway, New York City.

HAROLD O. SMEDLEY is now employed by the Skelly Oil Company in their Wichita, Kansas, office.

HUGH D. MISER, of the United States Geological Survey, Washington, D.C., has been spending two months visiting Survey parties in the field and continuing his studies in the Ouachita Mountains of Arkansas and Oklahoma. He visited field parties in Arkansas, Kansas, Texas, Oklahoma, North

Dakota, and New York. He reports that nearly 50 geologists have been employed for periods ranging from 5 months to a year on oil, gas, and coal work.

EVAN JUST, formerly of the New Mexico School of Mines, Socorro, New Mexico, is now petroleum engineer with the Carter Oil Company at Oklahoma City, Oklahoma.

The second Fall Meeting of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers will be held at the Mayo Hotel, Tulsa, Oklahoma, October 12–13. H. H. POWER, chief production engineer of the Gypsy Oil Company, Tulsa, Oklahoma, who is chairman of the production engineering committee, announces that J. VERSLUYS, professor at the University of Amsterdam, Netherlands, will present a technical discussion of "Energy Relationships in Oil-Bearing Formations," and CECIL MAY, of the Anglo-Persian Oil Company, Ltd., London, England, will present a paper, "The Efficiencies of Flowing Wells."

BEN F. MORGAN, formerly of Falls City, Nebraska, has been employed by the Stanolind Oil and Gas Company, and may be addressed at 1132 Milam Building, San Antonio, Texas.

At the regular monthly meeting of the San Antonio Geological Society, Monday evening, August 6, W. C. BLACKBURN presented a paper on "The Hilbig Field, Bastrop County, Texas."

JOSEPH L. ADLER has resigned his position as assistant professor of geology at the Michigan College of Mining and Technology, and may now be addressed at 1517 Branard Street, Houston, Texas.

JOHN E. GALLEY, geologist with the Shell Petroleum Corporation, and formerly at Tulsa, Oklahoma, has been transferred to Amarillo, Texas.

FRED H. WILCOX, formerly of 15 Charleston Street, Wellsboro, Pennsylvania, may now be addressed at the Magnolia Petroleum Company, Geological Department, Midland, Texas.

WARREN B. WEEKS, geologist with the Phillips Petroleum Company, Bartlesville, Oklahoma, is now at Amarillo, Texas, and may be addressed at Box 665.

H. I. TSCHOPP has changed his address from Carel van Bylandtlaan 30, The Hague, Holland, to Cia. Pet. Shell Mex. de Cuba S. A., Oficios 18, Habana, Cuba.

JOHN WELLINGTON FINCH, former secretary and director of the Idaho State Geological Survey, Moscow, Idaho, has been appointed as director of the United States Bureau of Mines, succeeding SCOTT TURNER, who has resigned.

THOMAS L. BAILEY, of Ventura, California, left recently for The Hague, Holland, to be gone four months. He may be addressed at Bataafsche Petroleum Mij., Carel van Bylandtlaan 30.

ALBERT D. MILLER, Department of Conservation, State of Louisiana, has been transferred from the Shreveport Division to the Lake Charles District.

R. C. LAMB, geologist with the Barnsdall Oil Company, has been transferred from Earlsboro, Oklahoma, to Hutchinson, Kansas.

SHIRLEY L. MASON has changed his address from Venezuela Gulf Oil Corporation, at Cuidad Bolivar, Venezuela, S. A., to 1617 Millard Street, Bethlehem, Pennsylvania.

FRED BRASTED, JR., geologist with the Stanolind Oil and Gas Company, has been transferred from Casper, Wyoming, to Goose Creek, Texas.

MARCEL E. TOUWAIDE has been promoted to manager of the Somiba Gold Mining Company, operating at Angumu by Stanleyville, Belgian Congo.

ROBERT B. CAMPBELL has changed his address from 220 Alta Vista, San Antonio, to 1904 Sterling Building, Houston, Texas.

The first Fall Meeting of the Petroleum Division of the A.I.M.E. will be held in the assembly room of the California Oil and Gas Association, Associated Realty Building, Los Angeles, California, October 5. L. C. UREN will discuss drainage areas and R. D. ELLIOTT will read a paper, "Physics of Electrical Coring Measurements."

WILLIAM A. P. GRAHAM, of the teaching staff of the department of geology at Ohio State University, Columbus, Ohio, died, August 11.

CHARLES L. DAKE, professor of geology in the School of Mines, and Metallurgy, University of Missouri, Rolla, Missouri, died, September 3, at Denver, Colorado.

THOMAS B. ROMINE, formerly with the Texas Pacific Coal and Oil Company, is now district geologist at Corpus Christi for the Sinclair-Prairie Oil Company.

C. D. CORDRY, the Gulf Production Company, Petroleum Building, Fort Worth, has succeeded Romine as secretary-treasurer of the Fort Worth Geological Society.

The Shreveport Geological Society will hold its eleventh annual field trip, October 5 and 6, starting from the Davis Hotel, Waynesboro, Wayne County, Mississippi, and covering the Jackson, Vicksburg, and basal Miocene.